



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

**IDENTIFICATION OF HUMAN FACTORS CONCERNS IN  
JOINT STRIKE FIGHTER  
AND TRAINING RECOMMENDATIONS**

by

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**IDENTIFICATION OF HUMAN FACTORS CONCERNS IN JOINT STRIKE  
FIGHTER AND TRAINING RECOMMENDATIONS**

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## **ABSTRACT**

Military aviation is the frontier of implementing leading edge technology. The major objectives of advanced technology aircraft are to increase pilot safety and mission efficiency; the Joint Strike Fighter, the most modern fighter aircraft under development, has many technological innovations for just this purpose.

A common fact is that technology develops and is used faster than it can be researched thoroughly. This thesis seeks to identify and mitigate potential human factors concerns related to the Joint Strike Fighter, before it is used in the air forces of participating countries. The objective is neither to blame nor defend the design of the aircraft.

Two surveys and an interview yielded the following findings: fighter pilots will use automation more in JSF than in their current types, the main LCD management will be key to mission efficiency and safety, the Distributed Aperture System should be addressed very carefully to avoid disorientation issues, and tactical decision-making skills will be more important and demanding.

New approaches for better automation training, more focus on data filtering, display management, prioritization skills, establishing robust standard operating procedures for DAS, and addressing the complex decision-making skills in more detail than the current training curriculums are concluded to be the major requirements of JSF pilot training.

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## LIST OF ABBREVIATIONS AND ACRONYMS

A/A	Air to Air
A/G	Air to Ground
AIM	Aeronautical Information Manual
ANCS	Aviate Navigate Communicate and System Management
AOPA	Aircraft Owners and Pilots Association
ASRS	Aviation Safety Reporting System
BVR	Beyond Visual Range
CNI	Communication/Navigation/Identification
COMAO	Composite Air Operation
CRM	Crew/Cockpit Resource Management
DAS	Distributed Aperture System
DEAD	Destruction of Enemy Air Defenses
EOTS	Electro-optical Targeting System
FLCS	Flight Control System
FLIR	Forward Looking Infrared Radar
FPM	Feet Per Minute
GPS	Global Positioning System
HMD	Helmet Mounted Display
HOTAS	Hands On Throttle and Stick
HUD	Head Up Display
IR	Infrared
IRSTS	Infrared Search and Tracking System
JSF	Joint Strike Fighter
LAX	Los Angeles International Airport
LCD	Liquid Crystal Display
LTM	Long-term Memory
MBT	Maneuver Based Training

MFD	Multi-functional Display
NTT	Negative Transfer of Training
PBL	Problem Based Learning
PVI	Pilot Vehicle Interface
RPD	Recognition-primed Decision-making
RWR	Radar Warning Receiver
SA	Situational Awareness
SBT	Scenario Based Training
SEAD	Suppression of Enemy Air Defenses
SEEV	Saliency/Effort/Expectancy/Valuable (A model of attentional allocation)
SFO	San Francisco International Airport
SOP	Standard Operating Procedures
TAA	Technically Advanced Aircraft
TACAN	Tactical Air Navigation
VOR	VHF Omni-directional Range
WM	Working Memory

## **EXECUTIVE SUMMARY**

Aviation is the frontier of implementing leading edge technology. Modern systems, displays and interfaces continuously enter cockpits to increase mission capabilities as well as safety and efficiency. However, it is up to the pilots to meet the promised objectives using the new systems.

The military requirements and budget concerns during the design and acquisition phases generally limit the conduct of relative research on human factors issues about the new systems; thus, many issues are still being addressed long after the acceptance of the assets or their subsystems. In some cases the drawbacks result in mishaps, and in others less efficiency than expected, until the human factors problems are solved completely.

Military aviation has the most demanding requirements among the aviation communities. The nature of the missions, the environment, and all additional stressors are the reasons for this fact; added to those factors is the need of military pilots to build more advanced skills than their civilian counterparts. The major task in commercial aviation is navigation, whereas navigation is only a tool to reach and return from mission areas in military aviation. Additionally, military pilots also accomplish air combat and night assaults out of many other military mission types. In order to succeed in their tasks, the military pilots use various enhanced systems that the commercial pilots don't.

Currently the Joint Strike Fighter is the most advanced fighter aircraft under development. Many allied countries contribute to the JSF project, and it is predicted that it will be the main asset of the NATO air forces in the coming decades. JSF has many innovations that will have impact on pilot performance. The increased use of automation (causing a role shift for the pilot), a big LCD display suite as the main PVI, a clear cockpit design with far fewer controls and switches, enhanced systems such as Distributed Aperture System (which allows pilots to "see through" the aircraft fuselage), and data fusion from many sensors

are among the main characteristics of the JSF cockpit. All of the aforementioned features are expected to cause some human factors concerns that must be researched and analyzed for safer and more efficient utilization.

The literature includes extensive research on automation, workload, attentional management, prioritization and the effects of many systems such as HUD and HMD on human performance. The objective of this thesis is twofold: to investigate whether there are areas prone to those same problems found in the literature, and to anticipate the problems unique to JSF itself. Other than trying to identify potential problems, the second objective is to propose solutions in the training phase that will mitigate the predicted issues.

The initial strategy of these authors was to investigate the potential problems regarding the transition phase. The JSF pilots will be chosen among the current types, and the main predicted concerns evaluated as they relate to the potential Negative Transfer of Training (NTT) issues during transition phase. The experiences of the pilots in their current aircraft types would make them prone to errors in JSF, and this possibility may result in mishaps or decreased efficiency. It was deemed possible and a major concern that the locations of the JSF cockpit controls and their operating procedures would conflict with the pilots' prior experience.

In order to identify the crucial areas of potential NTT and initiate the possible solution building process, the authors traveled to the Lockheed Martin facilities in Fort Worth, TX. The trip provided some opportunities to investigate the subject. These authors were able to experience the unclassified simulator, conduct a preliminary survey with fighter pilots who were experiencing various missions in the full mission simulator, and interview those pilots about their opinions. While expecting to return with all required information to complete the thesis with solutions, the authors found that the major problematic areas were quite probably different than those predicted as NTT during transition period. The participants and the authors mostly agreed that NTT will not be an important issue, but that role change, new systems and Pilot Vehicle Interface will be the

crucial components about the potential concerns. Thus these authors decided to investigate the problem identification process deeper; otherwise the solutions would not address the actual issues.

A follow-on survey was formed with multiple-choice questions in Likert scale, as well as open-ended questions to cover any missed issue in multiple-choice questions. The objectives were to identify the potential concerns robustly, and take opinions about the solutions. The following areas emerged as potential concerns: automation is predicted to be used in JSF much more than in current types, the Distributed Aperture System (DAS) is predicted to have some concerns if not addressed properly during SOP building and training periods, and the big LCD display suite management and tactical decision-making is predicted to be crucial for mission safety and efficiency. To adapt to the role change properly and build the requisite cognitive skills to operate the enhanced systems in JSF (with its different PVI) are thought to be the main challenges to training and following JSF pilots throughout their careers.

The literature is full of studies about problems in cockpit automation, but mostly in commercial aircraft. The JSF is predicted to be the first fighter aircraft with considerable automation use; thus the findings of the literature can be tailored to confront any problems about the automation in JSF. Similarly, decision-making skills, workload, attentional resource management and prioritization are well studied, and the related findings from these studies can be also used for JSF as required. The only predicted problem that has not been researched directly is the use of DAS, because it has never before been installed in cockpits.

A better approach to problem identification and building solutions could be utilizing objective methods such as experiments. But the security issues about the JSF project excluded that option in this thesis, and the literature and background of the participants as well as authors were the basis for the solution recommendations.

This thesis follows a bottom-up approach to generating training recommendations; the potential human factors concerns are predicted by the surveys, training objectives were established to mitigate the potential problematic concerns, and both findings of literature and operational background were utilized in order to recommend ways to address the objectives during the SOP building and training periods.

The research literature review, subjective reports by the participants and operational experiences of these authors formed the basis for the recommendations to pilot training in JSF. A revision of the traditional training curriculums is recommended to address both the potential automation-related problems and to ensure that the pilots build relevant cognitive skills, while utilizing the ground training devices as much as possible.

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# **I. INTRODUCTION**

## **A. PROBLEM STATEMENT**

Aviation is one of the leading application areas of technology development. Either it is the source of inventions itself, or implements already developed technologies faster than most of the other communities. These technological advances are reflected in cockpits mostly as increasing automation, new flight displays, and advanced avionics. The increasing number of sensors provides much more information to the pilots than ever before. Before, pilots were required to handle the throttle, stick, and a few manual systems. However, with the development of technology, the systems become more complex and have more sensors with greater range. These systems used in modern cockpits include radar, Radar Warning Receiver (RWR), jammers, weapon and flight management systems, etc. The implementation and upgrade of these systems raise the issue of their management, which resulted in the evolution of the conventional throttle and stick into the more complicated Hands On Throttle and Stick (HOTAS) system.

The dramatic increase in mission effectiveness is undeniable. However, these improvements in systems were associated with human factors issues, besides their benefits. The fundamental task of pilots is still the same—to fly safely, to evaluate the displays and information presented on them, and to use this information effectively to make the best available decision. One could wonder where the human factors issues arise from if the task of the pilot is still, in essence, the same. The best way to answer this question would be to consider the differences in pilot-vehicle interfaces (PVI). Earlier, there were separate displays for each particular source of information, and the pilot switched his attention between displays frequently to continuously track and evaluate his situation in the tactical arena. On the other hand, most of the flight instruments used in cockpits were manual and analog. Recently, with the advance of Liquid Crystal Display (LCD) technology and sensor technology, engineers could

produce more effective ways of information presentation, not to mention the ability to gather more and various kinds of information that were not considered before.

The pilots have access to much more information, but filtering the information to suit the specific tasks became an issue, as is managing the displays. Automation itself also caused some new problems for pilots. On top of all these advancements, 5<sup>th</sup> generation fighters, particularly the Joint Strike Fighter (JSF) bring even more modern and new systems to life. Increased sensor and data fusion and the Distributed Aperture System (DAS) (which enables pilots to “look through” the fuselage in a full 360-degree arc) are among those modern systems. It also has more sophisticated automation as well as a relatively clear cockpit with fewer controls compared to older aircraft.

There is a need to identify and understand the Human Factors concerns of the Joint Strike Fighter clearly and robustly before addressing them in proper ways. Some of the questions are “How will the pilots filter the data and focus only the required ones?”, “What kind of new skills will be needed for new generation fighters,” “Which areas of JSF are going to cause problems to the pilots, and thus need to be addressed carefully during training?”, or “What kind of concerns can be predicted about pilot-autopilot interaction in JSF?” Identifying the problems and important concerns and addressing them properly will allow pilots to benefit from the new assets more safely and efficiently.

## **B. MOTIVATION**

When examining the human factors in aviation, one can find out that most of the regulations are based on previous accidents and mishaps. Adaptation to newly exposed systems, technologies and tactics brings previously unknown issues that generally result in safety problems, accidents and even loss of aircrew. The majority of these problems in the past can be seen as negative transfer of training in the transition phase, because the systems operated with more or less the same logic only with different displays and controls. Therefore,

previous experiences resulted in some safety problems due to new cockpit controls. However, the issue now is different. Advanced technology has offered new systems that are dramatically different from their predecessors, both in operating logic and pilot interface. The motivation of this thesis research is to anticipate the possible human factors issues beforehand, which might help to avoid possible accidents and mishaps, as well as increasing the effective use of systems.

### **C. OBJECTIVES**

This thesis attempts to provide a comprehensive insight into the human factors issues of JSF. The main objective is to identify the important and problematic human factors concerns of JSF. After the identification of the problems, it will be possible to address them and propose solutions to those areas in order to increase the safety and effectiveness during the transition periods and thereafter. One way of proposing solutions is to use the literature and previous knowledge, and the other way is to address them with specific experiments, or field studies. The last and undesirable way is to learn them via experience, and the intent of this thesis is to identify and address them before any hazardous situations happen.

### **D. THESIS ORGANIZATION**

1. Introduction. This chapter gives a general outline of the work and defines the problem the authors are trying to solve.
2. Related Work and Background. This chapter discusses the primary concerns related to pilot workload, cockpit automation and attentional resources theory and summarizes literature reviews on these fields. The capabilities and key features of JSF are also discussed in this chapter.

3. Methodology. This thesis followed survey methodology for research, and conducted two surveys and interviews. This chapter explains the background ideas and structure of the preliminary and follow-on surveys, as well as the interviews.
4. Results and Discussion. The results of the interviews and surveys are provided and discussed in this chapter.
5. Conclusion and Recommendations. After reviewing the key findings of the surveys and interviews, the establishment of relevant training objectives and how to address them in pilot training topics are discussed in this chapter. Additionally, recommendations for future research are also included.

## **II. RELATED WORK AND BACKGROUND**

With evolving technology and growing experience in all scientific fields, the literature expands continuously. This sometimes creates new fields; at other times it enriches the content of an existing one. The main consequence of this phenomenon is the increase of required expertise in almost every research, project, or field of technology.

The scope of this thesis is the Human Factors concerns in the JSF cockpit. As mentioned above, even this scope entails having information about many Human Factors subfields. Many researchers have studied modern glass cockpits, and two major topics have emerged from the literature about the Human Factors in such an environment: cockpit automation, and pilot workload along with management of attentional resources.

Cockpit automation is a well-studied topic in commercial aviation, but is relatively fresh for military aviation, especially for fighter cockpits. Today, almost all commercial airplanes have very sophisticated automation systems, and as Olson (2001) reported, they are able to perform all tasks but takeoff and landing automatically. It is legitimate to say that even takeoff and landing can be performed with newer automation capabilities. Automation has also brought some problems along with its solutions, and all of those have been robustly researched in the literature.

The other accepted truth is the increasing workload for the pilots. Pilots must learn and use many more systems than before, and the structure of the systems is more complex. All these facts, with the increasing demands of the mission environment, result in increased pilot workload in the cockpit. Both the designer and operational communities strive to build suitable systems and operational procedures, but there are many causes for concern. Sometimes

technology develops faster than humans can adapt, thus adding work rather than subtracting it. Workload is a well-known and studied topic by the human factors and ergonomics experts.

With the increased level of automation, and many more sophisticated and revolutionary systems, the JSF will also require focus on these topics. For this reason, the related work and background section of this thesis is divided into two subsections, including cockpit automation and pilot workload.

## **A. COCKPIT AUTOMATION**

The role shift of the pilots was one of the objectives of the Lockheed Martin team; Kent (2006) quoted Skaff's statement that, "The F-35 cockpit design is driven by the desire to return the pilot to the role of tactician" (para. 12). This goal alone makes it worthwhile to study findings about automation for developing JSF training. This chapter reviews the findings of research literature related to cockpit automation.

### **1. Introduction to Cockpit Automation**

Before investigating the human factors concerns, safety and effectiveness aspects of the cockpit automation thoroughly, one has to understand the reasons for integrating automation with the cockpits.

Sarter, Woods and Billings (1997) listed improved economical efficiency and precision as two of the general benefits of automation. However, they also add that these benefits have introduced other problems, and the importance of the human user has been reinforced, even in the highly automated cockpits. They claim that more training should be added to the curricula to address the automation-related problems in order to reduce the costs of the benefits.

Another obvious reason is the increased workload in the modern glass cockpit. Most modern cockpits contain many more systems along with more sophisticated menus and operational procedures. In some situations, performing all of the required tasks is beyond users' capabilities. For instance, most modern fighter aircraft have Flight Control Systems containing certain safety limitations;

they do not allow pilots to exceed structural g limits. The designers are aware of the workload and stress levels during air combat, and because there is a great possibility that the pilot may forget to monitor the g levels in such situations, they automated the FLCS to limit the pilots instead.

After the overview of the main reasons for automation in cockpits, it can be seen that increased automation is inevitable for future platforms. There is no strong debate on the necessity of automated systems, but naturally it has been changing the pilots' tasks and workload. A rough comparison would be a shift from performing fewer and simpler tasks alone to performing more and more complicated tasks together with automated systems. The automated systems can be the autopilot navigating the airplane and the radar system performing locking and tracking tasks, freeing the pilot for other imperatives.

Sarter, Woods and Billings (1997) said of the common role change in the modern cockpits that, "Introduction of new automation has shifted the human role to one of monitor, exception handler, and manager of automated resources" (p. 2). The same role shift is also acknowledged in the military aviation community, and Olson (2001) is one of the researchers who agreed that the shift in the role of pilots with increased automation will be from performing all the tasks to supervisory control.

The role shift in the cockpit requires pilots to perform their tasks in a different way than before. Furthermore, they have to develop the corresponding skills and abilities to be successful in their new role. It is known that actually performing a task versus observing it (vigilance task) offers an improvement in terms of performance. It is a common fact that humans are not so effective in vigilance tasks. Rigner and Dekker (2000) acknowledged the effects of automation on required pilot skills. They said that the pilots have become supervisors in the cockpit, observing and maintaining the operation of all other systems and components. In order to succeed in their new roles, pilots should

absorb more knowledge and build many more complicated skills. Managing their attentional resources, and filtering and evaluating required data, are some of the important skills they need.

An interesting point between Sarter, Woods and Billings (1997), and Rigner and Dekker (2000) is the need for cooperation with other systems or resources. Sarter, Woods and Billings (1997) confirmed the importance of the human-machine coordination, and acknowledged that the relationships and reliance factors are highly complicated in modern systems. The pilots should develop satisfactory mental models about the automated systems. There are many types of complicated relationships between the systems themselves and between the pilots and the automated systems. Pilots need to know and direct the systems interactions, and be aware of the all inputs to and outputs from the autopilot during the flight.

Apparently, the skills emerging with the use of automation are the supervisory skill to observe the automated systems and the coordination and cooperation skills to work with the automated systems as if they were another agent in the cockpit. There are many instances proving that the implementation of automation in the cockpits can be problematic. Olson (2001) reported one of the important findings about the pilot-autopilot coordination: in most cases, after the automated system starts to perform a task, the pilots tend to forget to control the related performance parameters. This finding directly shows that the pilots do not observe the automation performance as they should. Initially, one can directly blame pilots, but this would be not the real solution, but an escape from the big picture. The problems should be addressed beginning with the design of the system, building the operational procedures, and training to control quality throughout the lifetime. The common problems of automation will be discussed in the next chapter, and the recommendations in the last one.

To provide a quick view of the big picture about relations in the automated cockpits, Spencer (2000) mentioned a beneficial model. The main idea of the model is to define the systems with the subcomponents of software, hardware,

environment and liveware. The liveware in the cockpit example is the pilot, and he interacts with all of the other components during the missions. The other components are: standard operational procedures, the software of the pilot vehicle interfaces, the aircraft and the related hardware, co-pilots, etc.

## **2. Definitions and Overview of the Automation Problems**

In order to understand and interpret the results of the research better, it is crucial to acquire enough knowledge about the terminology and common knowledge of related fields. This is also applicable to cockpit automation, about which there are several commonly accepted definitions. These definitions, along with some examples will be reviewed in this chapter to provide the fundamentals needed in the following sections. Although there exist many other phenomena about cockpit automation, the mentioned ones are the most important and recurring ones in the literature.

### ***a. Mode Awareness/Confusion/Errors***

The reason to mention these three terms together is the fact that they are inextricably inter-related. They are used interchangeably in many studies, and are based on the same phenomenon.

Today, most of automated systems consist of many operating modes and menus. They are also capable of making many decisions and performing tasks independently. As mentioned before, it will be legitimate to think that there are two actors in a highly automated cockpit, and therefore a very logical issue is the coordination between them. In other words, pilots should be aware of what the other decision maker is doing at all times, and how it also interacts with the other systems. This straightforward logic is self-explanatory, and even if one does not have any knowledge about cockpit automation, he can conclude that “mode awareness” means continuously to be aware of the mode in which the system is operating. Similarly, if the operator is confused about the mode of the automation, it is “mode confusion;” and if he commits errors because of this confusion they are “mode errors.” Even though they seem very

straightforward, there are many valuable and important data about mode errors in the literature, and these will be discussed later in this study.

Sarter (2000) is one of the researchers who has studied cockpit automation. She said that the pilots generally do not have a through understanding of the structure and operational procedures of automated systems, and when combined with “low observability,” this creates various problems in flight (p. 233). Yet another additional system is then implemented to help pilots, with yet greater need for additional visual and mental resources.

The reasons for the mode awareness problems in Sarter’s study are the knowledge problems and low observability; furthermore, Sarter, Mumaw, and Wickens (2007) defined four major factors causing the automation problems in glass cockpits. The first one is related to the lack of capturing the attention of the pilots. Most automation systems have poor design and fail to provide sufficient and easily observed feedback to pilots. Also, the increased number of automated actions shunt the pilots increasingly into a supervisory role; the automated systems initiate more actions without any pilot consent, which makes it harder to track the modes. Another reason is the “high degree of system coupling” (p. 348). In general, not only the modes and complexity of the automated systems, but also the number of other systems have increased. These developments conspired to hinder the pilots’ ability to track and understand the interactions between the automated and other systems. More systems became related to the inputs and outputs to automation. The last contributing factor is the knowledge of the pilots. It was found that the pilots’ lacked robust understanding of the automated systems, and were prone to mode awareness problems.

When the operator takes an action as a result of thinking a system is in one mode, where it is actually in another mode, this is a “mode error” (Sarter et al., 2007, p. 347).

Examples will give a better insight on the mode awareness concerns. A mode can be a navigation mode of an autopilot system, or a tracking mode of a fighter's fire control radar. In both situations, it is very crucial to be aware of the mode of the automated system. Most of the evidential accidents about the automation can be found in the literature. Sarter (2000) mentioned two of these incidents. In the first one, the captain changed the descent mode of the autopilot, because it deviated from the approach track, and switched to the "heading select mode." Because the vertical operation part of the autopilot was working with the lateral part, the change resulted in an unintended 1800 fpm descent, which was considerably in excess of the proper rate for landing. Thankfully, the warning system in the aircraft and the crew of the control agency together prevented a potential accident. In the second example, the pilots thought that they were making a 3.3 degrees descent, whereas the autopilot commanded a 3300 fpm descent; the crew and passengers were not as lucky as in the first example, unfortunately, and the plane crashed. These real life examples indicate the importance of mode awareness in autopilot systems. Because the common approach is not to perceive the autopilot as a critical system, the aviation community must make sure to take the preventive measures.

Although there are no examples about mode confusion in fighter jets, it does not mean that fighters will not have those problems. The main reason is the adoption of automation. Commercial aviation already implemented the automated systems, and most of the tasks can be performed with the autopilots. But to date, the fighter cockpits do not contain the same degree of automation. The autopilot and other automated systems are not used and implemented as in the commercial aviation community. But this trend is changing, as the authors observe in the JSF example. Not just the autopilot, but also even the auto-mode radar may cause problems with mode confusion. For instance, if the digit on one side of a radar target symbology represents the altitude in one mode, but another

data in another mode, the pilot may build an intercept strategy depending on the wrong interpretation of the data, which in turn may mean life or death.

***b. Decomensation Incident, Automation Omission and Commission Errors***

The “decompensation incident” occurs when automation tries to handle some problem or abnormal parameter up to a point, and then quits handling that problem. In such situations, pilots are liable to become aware of the problem too late (Sarter et al., 1997, p. 7). This definition is similar to the definition of the “automation omission error.” Mosier, Skitka, Heers, and Burdick (1998) explained the automation omission error as an error caused by a lack of correct information about an abnormal situation during automated operations (p. 51). The example they give is an airline mishap in 1996. The airplane was controlled by the autopilot for level flight. One of the aircraft engines failed, but the autopilot compensated for the loss of thrust caused by that engine, and as the aircraft continued to fly level, the pilots did not understand the abnormal situation. Once they disengaged the autopilot, however, the airplane entered into an abnormal descent.

Mosier et al. (1998) also explained the automation commission errors. These errors happen when pilots monitor contradicting behaviors between other and automated systems. The example they mention from the literature is a study with an experimental design. The pilots were given a scenario with contradicting cues. During takeoff, the automatic checklist directed the pilots to shutdown an engine, though the truth as shown by traditional displays was different. The other engine was malfunctioning, but 75% of the participants took improper action and trusted the automated system without cross checking it with traditional instruments. Both types of errors happen because of the lack of cross checking of other flight instruments with the automated ones. This finding, combined with the finding that pilots do not include status checks of automated systems in their routine checks (as they did with other systems and aircraft performance variables) indicate a problem in automation management.

### **c. *Clumsy Automation***

One of the major promises of automation was reduced pilot workload—because the pilot would perform fewer tasks due to automation, the overall workload could be expected to decrease. This is a topic for debate, and Sarter et al. (1997) explained the definition of “clumsy automation” by Wiener (1989). They explained that “many automated systems support pilots most in traditionally low workload phases of flight but are of no use or even get in their way when help is needed most, namely in time-critical highly dynamic circumstances” (p. 3). This will quite probably be the case in the new fighter cockpit environment. The intent of the authors is not to say that the fighter cockpits have clumsy automation, but that the environment is generally as mentioned above: timely, critical and highly dynamic (Sarter et al., 1997). Another important change in the fighter cockpits is the nature of the missions. The new missions require many demanding and dynamic tasks such as air combat, SEAD, and DEAD missions, whereas the navigation is the only task in commercial aviation. This concern will also be discussed in the following chapters.

In addition to the aforementioned problems, Doherty (2001) reported “boredom” and “complacency” (p. 22). Because the pilots feel that the reliance on them by the systems is decreased due to automation, their performance tends to decrease with the automation-related tasks. The effect of boredom is that it causes the stress level to be lower than the optimum, and the effect of complacency is the increased demand for cognitive sources. The boredom can cause a decrease in pilots’ SA, whereas the complacency can cause task saturation under highly dynamic and high workload situations.

The main objective of this section was to provide the readers with fundamental knowledge about the human factors concerns about cockpit automation. The findings will be discussed further in the next sections.

### **3. Findings About Cockpit Design**

Inevitably, as more and more technological systems are used in the cockpit, many human factors concerns accompanied them. Automation is one of the major evolutions among the modern technological systems in glass cockpits. It has two aspects: hardware and software. In some instances, pre-existing systems have been digitized, and algorithms have been specifically coded to automate many tasks. In other cases, hardware is designed specifically to automate some tasks, such as autopilots. Regardless of the method, the process has had a major impact on human factors in cockpit design.

Spencer (2000) explained the environment in modern glass cockpits as “Complex cockpits, faster, more capable aircraft, airspace saturation, and increasing air traffic control requirements create the environment and conditions conducive to mode confusion” (p. vi).

The reason to include this chapter is neither to defend nor to criticize the design of the JSF cockpit, but to identify the potentially problematic areas. One of the commonly accepted impacts is the shift in the pilot's role in the modern cockpit. This is a topic studied thoroughly under CRM and other automation research. Spencer's model (described previously) for the interactions between pilot and components in the cockpit treats the pilot as essentially another system. This systems approach may provide designers a framework to consider the relations in the cockpit because, as he notes, the tendency with modern cockpit design is to prioritize the automated systems, whereas a better way is to use a human-centered approach (Spencer, 2000). As seen also in many other studies, the human has not been the major concern in modern cockpit design. However, the pilot is still responsible for safe and efficient operation of the aircraft. Some steps forward can be seen in many cockpit designs, but there is room for improvement on this issue.

Likewise, another consequence of the automated cockpits is the shift in the type of activities conducted by pilots. They are not actively performing, but

observing the automated tasks, and it is commonly accepted that humans cannot maintain their performance during longer periods of vigilance tasks. Davies and Parasuraman (1982) are among the researchers who studied this phenomenon by questioning the findings' relevance in real conditions. They explain the shortcomings of some findings of fully laboratory experiments, but also agree with the decreasing performance over time shown in many other studies. With the tasks the autopilot performs, and the pilot observes, there can be shortcomings due to vigilance. That raises the question of the number of tasks to be automated during design. Spencer (2000) reported the same issue, and noted that there is a threshold for the best performance in automated cockpits. Basically, up to this threshold more automation results in better performance. But after this point, if additional tasks are also automated, the pilot performance suffers due to SA problems. He added that "Researchers recommend balancing human involvement (increased situational awareness) with automation efficiency" (p. 12). This conclusion may be valid in general, but establishing a balance will be harder in dynamic situations. All of a sudden, additional threats may pop up, thus shifting the balance point for that situation. With these challenges in mind, the human involvement should at least be taken into consideration during design and operational phases.

Since more systems are in use in modern cockpits, the users have to do more with their same cognitive resources. In general, mental resources are a concern for pilot workload studies, but the over-reliance on the visual resource is becoming a more important concern. The pilots monitor basic flight instruments, navigational and communicational systems, Air to Air and Air to Ground Radars, Radar Warning Receivers, automated systems and many more, and they use their visual system for all of these tasks. Increasingly, the question is whether the pilots' visual resources are able to handle this workload in all of the required situations in the cockpit. In fact, the automated systems also demand visual resources in many applications, adding yet another system to help pilots but contributing to a need for additional visual resources.

Sarter (2000) tried to come up with solutions for decreasing the attention load on visual resources. In order to mitigate the problems with automation, one has to understand the reasons for the problems during automation use. Sarter (2000) reported one of the findings of the study by Sarter and Woods (1995), where the pilots did not implement the automated systems checks to their routine procedures, but mostly observed them depending on their “expectations of specific automation behavior” (Sarter, 2000, p. 234). She concluded that this approach will fail if the pilot is not fully aware of the status and modes of the autopilots (Sarter, 2000). The reason may not be the overload of visual resources, but additional resources can be addressed in order to provide pilots with increased awareness about the automated systems.

Another issue Sarter (2000) noted is the problems in display designs of automated systems. The modern trend has been to convert the round shaped analog displays to “so-called tape instruments” (p. 236), but the pilots, at a glance were able to retrieve the required information from the round displays. She reported one of the findings in a study of Sarter and Woods (1995b), that pilots expressed difficulties about the non-round displays. They added that it took longer to get the data from tape displays. That finding points to the issue of additional cognitive processes and the increased demand on visual resources. This issue is important even if the automated systems do not have tape displays. The common use of tape displays is in flight performance parameters, and if the autopilot is controlling the airplane, those displays become one of the crosscheck displays to the pilots monitoring the automated systems.

Another automation aspect of cockpit design is the reliance on the automated systems and their programmed algorithms. Automation is intended to provide safe and efficient operations, but there remains the risk of relying on the technology too much. Dalcher (2007) studied this issue by examining a case in his research where the autopilot limited the pilot to an extent that he couldn't recover the aircraft; in that case, the automation itself caused the aircraft to crash. Dalcher believes that the goals with the highly automated systems are “...

the superior computational capability coupled with elimination of human error, and the reduction in work overload and lack of dependability,” and then acknowledges that there may be many situations where the automated systems lack the flexibility to handle difficult situations (p. 352). This is related to the algorithms and design of the automated systems. Many tasks are automated, but sometimes it may not be possible to consider all of the possible situations or inputs and outputs when designing the responses of the automated systems. Thus, the designers should be very cautious while choosing and implementing the tasks to be automated.

After expressing the importance of involving users in the design and operational considerations, looking to the user side of automation design will provide valuable clues. Tenney, Rogers and Pew (1998) conducted a study via survey methodology, and tried to capture the pilots’ opinions about cockpit automation. The following findings are listed in their study. First, pilots’ preference was that the automation should be a cooperative design, rather than highly automated cockpits that make pilots mostly observers. Pilots want automation in their complex tasks, but they desire a human-centered approach, and cooperation among the agents in the cockpit. However, they reported some modes of automation as “...producing a high mental workload.” The pilots found the most important features to be “simplicity and reliability” (p. 103). The reliability is more related to design issues, and must be considered from the conceptual design phases to the end of the life cycle of the products. But it is not planned and implemented by the users. This is not the case in simplicity. Simplicity is a usability issue, and the user will be directly affected by it. Simple systems will decrease the workload of the operators, and free time for other tasks. Furthermore, users will be prone to fewer failures with easy-to-use systems. It is very apparent that the pilot opinions basically confirm the findings of the aforementioned studies, further validating those findings.

The types of automation play a great role in assessing the attentional pattern of pilots and their mental approach to automation. Wickens (2000)

divided automation into two main groups: “reliable” and “unreliable.” He defines reliable automation as “that which does what it was intended to do” (p. 4), and suggests that reliable automation causes either “attentional tunneling” or “cognitive tunneling,” depending on the cognitive process.

The same phenomenon is named by Wickens (2000) as “action tunneling” if it happens following cognitive tasks about automation, since the automation is naturally going to direct the pilot’s attention to the automation’s preferred choice of action. Wickens (2000) explains this term as an alternative action preferred by automation rather than the pilot, which, however, is not the best alternative at the moment because of considerations that are not related to automation. In this case, instead of devising an action himself, the pilot’s attention is going to be allocated to validating the automation’s recommended action.

Supporting this suggestion, Wickens (2000) observed this phenomenon in an experiment in which pilots did the pre-flight check with wearable-computers. The experiment results showed that the detection of unidentified faults decreased while the detection rate of computer-identified faults increased. The information that is considered to be significant and is highlighted by the automation might cause the pilot to ignore other information that is not highlighted at the moment, but is as critical as the highlighted one.

Eventually, says Wickens, the pilot will begin to trust in automation more than in himself; he will not question the validity of automation-inferred data and actions as much as he should. This will lead to the failure to detect an automation problem, degrade the level of situational awareness of the pilot, and cause him to lose his skills that have been replaced by automation. The loss of situational awareness due to the loss of automation will cause the pilot to evaluate the raw data and the systems outputs either slowly or not at all. In any case, the pilot will fail to consider all possible alternative actions due to this deprived situational awareness caused by “automation complacency.”

#### **4. Findings About Pilots' Strategies of Automation Management**

Sarter and Woods (1992) mention the commonly accepted perspective of Billings (1991), that the job of the pilots has shifted to that of a supervisor only actually performing in abnormal procedures; at the same time, they also discuss that taking the human user out of the loop is a risky decision that will affect the concentration and "awareness" of the pilots negatively.

Sarter and Woods (1992) conducted a study in 1992. They report that even the pilots who used the automated systems more than one year sometimes had difficulties operating and understanding the automated systems, and they recommended that enough time should be given during pilot training to help them build a thorough understanding of the automated systems, and also to address the pilot-autopilot "coordination" during training. This was one of the earlier studies, and pointed out an important problem about the pilot-autopilot interaction. It is legitimate to think that the automated systems were not as complex then as they are today; thus, even with less complex systems offered the same problems. But another factor could be the fact that automation was in its earlier stages, and therefore that robust training and operational procedures had not been fully developed. So, reviewing further studies may make the subject more clear.

Sarter and Woods (1994) also conducted an objective study, with a typical flight scenario from LAX to SFO with a part task trainer. They injected events related to automation during flight, and recorded pilots' reactions to a prepared list. Using this method, they also asked participants questions about automated systems during low workload conditions. They tried to capture the pilots' knowledge level in a realistic environment rather than in isolated situations. They report that pilots were comfortable in performing the standard basic tasks in cockpits such as "intercepting a radial, building or executing a holding pattern....," but they experienced difficulties during the tasks requiring comprehensive understanding about the automation such as "aborting a takeoff at 40 knots with auto-throttles on" and "...anticipating when go-around mode becomes armed through landing....," both indicating that the pilots have insufficient knowledge

about the automated systems, even though they think that they have enough knowledge (p. 14). The interesting point is the lack of knowledge and operational capabilities about automation even in some emergency situations. Even if the autopilot may not seem complex and important, the mishaps and crashes express its importance.

Based on the findings, Sarter and Woods (1994) suggest improved training to address developing automation skills. The pilots not only have to understand the technical structure of the systems, but also be able to make decisions under high workload conditions. This requires a thorough understanding of the functions and interrelations of the automated systems. This is an issue to be addressed properly in realistic environments, via scenarios. The knowledge and operational abilities of pilots should be stressed with these scenarios in order to help them build proper mental models.

Sarter, Woods and Billings (1997) claim that newer approaches in automation training should not only include increasing the training time, but also modifying the nature of the content. The two important traps about automation management reported in their findings are the subjective opinion of the pilots that they have enough capabilities and knowledge, and their tendency to build only limited skills that they try to apply to all situations. These two points mask the truth for pilots, and in case of a life or death situation, it may be too late to discover their deficiencies in automation.

Mosier, Skitka, Heers, and Burdick (1998) investigated “automation bias” during automated tasks performed by commercial pilots. They conducted an experiment measuring the “automation omission,” and “automation commission” errors of the participants during automated tasks. For instance, commission errors happen when pilots monitor contradicting behaviors between traditional and automated systems. The example they give is when pilots were given a scenario with contradicting cues. During takeoff, the automatic checklist directed the pilots to shutdown an engine; the truth as shown in traditional displays was

different. The other engine was malfunctioning, but 75% of the participants took improper action and trusted the automated system without cross checking it with traditional instruments.

Both omission and commission errors happen because of the lack of cross check of traditional flight instruments along with automated ones. This finding, combined with the finding that pilots do not include a routine status check of automated systems as they do with traditional systems and aircraft performance variables, again indicates the problem of automation management. Additionally another interesting finding of their study is: "...pilots who reported a higher internalized sense of accountability for their interactions with automation verified correct automation functioning more often and committed fewer errors than other pilots" (Mosier et al., 1998, p. 59).

Another study that reports similar findings was conducted by Bjorklund, Alfredson, and Dekker (2006). They conducted an experiment to study the relation between the monitoring strategies of the pilots and mode awareness. They collected eye-tracking data, while giving participants mode transition and asking for status of autopilot mode. The results supported previous findings that pilots did not follow the standard operating procedures, but pursued their own strategies driven by expectations to monitor the status of autopilot. They report that the pilots did not capture 40% of the mode transitions. The pilots again did not monitor the autopilot via the SOP, and during their routine checks.. This study was conducted in 2006, and the findings are still similar to the studies done in the early 1990s. With time, one expects that the training and operational procedures will have addressed the common problems about automation, because it has been widely used for decades. However, studies indicate the existence of the same problems. Additionally, this is not the only recent study indicating the same results.

Sarter, Mumaw, and Wickens (2007) conducted a study researching the same issues. In their study, they mention the previous studies and point out that most of them used subjective measures about the pilots using the automated

systems. One of the shortcomings of previous studies using objective measures was the small sample size. In their study, they had a sample size of 20, and used a high fidelity part task trainer suitable for their study purpose. They had two types of events, experimentally injected and others. Other type of events occurred during the flow of the experiments themselves, and were also recorded for analysis. They also recorded the eye movements besides asking questions to capture the level of pilots' understanding about automated systems. The actions taken by the pilots during the experiments were recorded with predetermined data sheets. Their findings are consistent with the previous studies. The pilots allocated considerably more of their attentional resources on basic flight parameters than the automated systems. Their automation awareness was much lower than their general awareness, and one of the reasons is that they failed to build robust mental models about the automation (Sarter, Mumaw, & Wickens, 2007).

## **B. ALLOCATION OF ATTENTION, WORKLOAD AND TASK MANAGEMENT**

Doherty (2001) pointed out the most important and obvious difference between commercial and military aviation is that the mission in military aviation goes beyond basic navigation. In addition, the real missions (intercepts, target bombing, Air Combat Maneuvers) are as not static as level flight in commercial aviation; thus, the workload and management of attentional resources are more demanding in military aviation.

### **1. Attention Theory**

Fleetwood and Byrne (2004) defined attention as a resource, and the way it is allocated is important because of limited resources.

Prinzel and Risser (2004) pointed out the three sub categories of attention, which are more dominant in aviation and Head-up Display (HUD) literature, as selective, focused and divided attention modes. (Prinzel III & Risser, 2004)

It is beneficial at this point to examine focused and divided attention modes a little bit more, to have a better insight about accidents. Prinzel and Risser (2004) examined these attention modes with space- and object-based theories. Space-based theory considers the distance between information sources, and suggests that the more these sources are away from each other the more eye movements will be required for scanning, thus resulting in a performance degradation due to increased scanning costs. It favors the information sources that are close to each other for attention to support the concurrent tasks requiring information from these sources. This theory, however, also considers the cluster effects; it will be possible to give equal attention to two sources if they are in “close spatial proximity,” according to Prinzel and Risser (2004). On the other hand, they claim object-based theories suggest that attention supports concurrent processing of tasks using information from sources that belong to the same object, defying spatial proximity.

Besides these, Prinzel and Risser (2004) also stressed the importance of different domains of information on attention capture. They state that processing of HUD facilitates a combination of these attentional theories and information domains. The near and far domain each require focused attention to extract information when switching between the domains, while following a symbology that is superimposed on a target (far domain) on the HUD requires divided attention.

Prinzel and Risser (2004) found that the presence of more symbology than is required for the current task was a factor making the attentional switching harder between near and far domains, due to increased clutter on the display, thus resulting in attentional capture or tunneling.

They further suggested that the redundancy of the information might be another reason for attentional tunneling. Evidence for this is that pilots extract the flight information only from the HUD because it provides more sensitive information, and use the environmental cues just for monitoring.

Another possible reason for attentional tunneling suggested by Prinzel and Risser is perceptual load. They stated that under increased workload conditions, it is more likely to observe attentional tunneling because pilots cannot scan and filter the unrelated and unnecessary data because of the high demands from attentional sources.

Prinzel III and Risser reported that “perceptual groupings” might be another reason for attentional tunneling. They pointed out evidence that pilots group informational sources according to their domains. This grouping is done perceptually, with near domain objects being stationary and far domain objects being in motion. Thus, this might be another explanation for why the far domain unexpected events are hard to detect. Pilots have difficulty in switching between these perceptual groupings.

## 2. Attentional Resources Considerations in Automated Tasks

Wickens (2000) referred to the following model to classify the data process stages in automation (Figure 1).

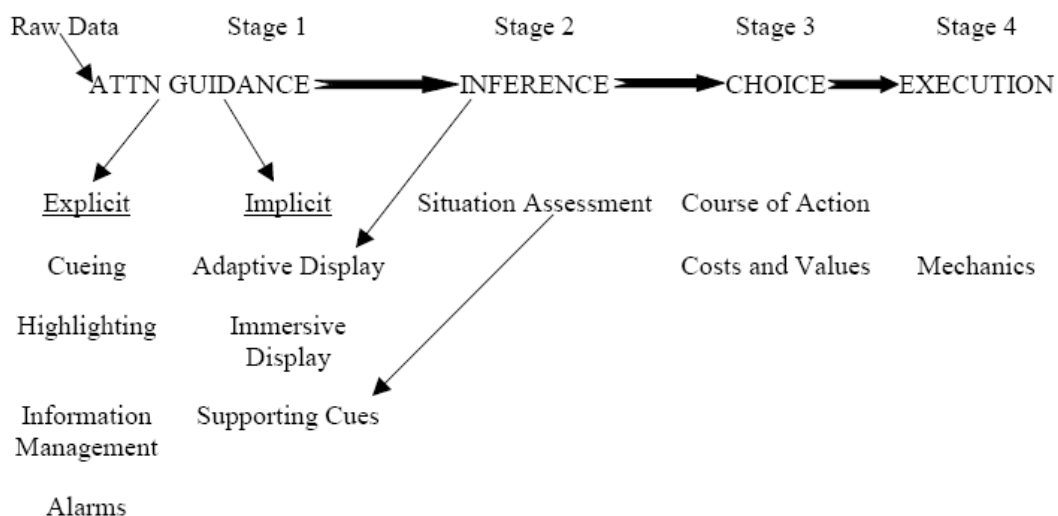


Figure 1. The parts of automation processing (From: Wickens, 2000, p. 2)

A thorough understanding of Figure 1 is necessary to understand the underlying reasons for attentional tunneling, and the tight relationship between automation and use of attentional sources.

This figure is also significant to observe the way in which the factors affecting the allocation of attention implemented in the information progression process. It might also give a basic understanding about the attentional patterns in an information rich environment. Therefore, it is considered to be beneficial to give a brief explanation of automation, and a description of this figure.

Wickens (2000) stated that, in the first stage, incoming raw data might be filtered by the system or selected to be in a certain form by the pilot. This raw data is represented to the pilot either explicitly or implicitly in many other forms, once automation determines it. All of these forms have the same effect on a pilot's attention allocation process: distracting him from the other sources of information, they direct a pilot's attention to a single point.

On the other hand, Funk, Suroteguh, Wilson, and Lyall (1998) noted that, in automation and attention relationships: "The attentional demands of pilot-automation interaction may significantly interfere with performance of safety-critical tasks (e.g., "head down time", distractions, etc.)" (para. 18).

### **3. SA, Workload and Task Management**

Endsley (1995) referred to her previous researches while providing the definition of SA as: "Situation awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (p. 36).

Doherty (2001) is one of the researchers acknowledging the additional required abilities for pilots in glass cockpits. One good example is the Distributed Aperture System in JSF. It includes several cameras all around the aircraft and the pilots are able to "see through" the fuselage in all directions. The DAS system may be prone to disorientation, which needs to be addressed in training. Doherty

(2001) also states that the inability to manage the ample data is the main reason for the “excessive workload errors” (p. 24). The pilots in JSF cockpit may be prone to this type of errors if they do not acquire the skills for managing the information in the portals in order to make their tactical decisions.

In another study related to the same issue, Spencer (2000) reports the importance of the time and informational overload factors in user performance, and adds that a University of Toronto study concluded that time pressure was more important than informational overload. Although it seems that these two factors are different, the distinction may not be so clear in real life. In many situations, higher informational overloads will make the pilots’ job harder, and they may need more time to filter and evaluate the data, and then make proper decisions. If one needs to study the effects of both factors in such situations, it will be hard to distinguish the effect of time pressure from the informational overload. Either way, there remains a common outcome about the effects of both, and there is the need to address the related problems during training, and to improve the pilots’ required skills for modern glass cockpits.

Many studies point to similar concerns, and have more or less similar conclusions about the changes in workload in modern glass cockpits. As a sensible general approach, Fiduccia et al. (2003) proposed a taxonomy of pilot tasks, dividing them into skills for flying the “Physical Airplane,” and those for flying the “Mental Airplane.” Generally, the former refers to aviating or basically flying the body of the aircraft, and the latter to operating all avionics, thus making tactical and complex mission related decisions. Fiduccia and his colleagues were in a team studying the human factors concerns in general aviation. Following the aforementioned taxonomy, they pointed out that the accidents related to modern systems fall into the “Mental Airplane” category, and that addressing this issue in training by means of hard, realistic systems scenarios should be mandatory. Coping with the information from all of the systems, and complicated mission types, the authors predict that JSF tasks will increasingly deal with flying the “Mental Airplane.”

Olson (2001) states that workload management should be addressed during high workload situations. In operational procedures and checklist items, enough time should be given for the pilots to activate and observe the automated functions. There might be two major aspects of automation with JSF. The first situation is when the autopilot commands the aircraft during high workload tactical mission phases. These phases are very dynamic, and the workload is generally very high. The pilot can easily focus only on the tactical displays and forget to observe the parameters managed by the autopilot at that time. Another issue is the dynamic changes in goals. The pilot can engage the autopilot during a Combat Air Patrol mission, and the goal at initiation can be maintaining a particular airspeed and a predefined track. But if the pilot suddenly sees an immediate threat, his new goal could include increasing the airspeed and performing high 'g' maneuvers. When transitioning to manual control, the pilot has to be aware of the current parameters and limitations of the automated system.

Funk, Suroteguh, Wilson, and Lyall (1998) suggest that task management in advanced and highly automated cockpits may be problematic. They cite an incident report (#92507) from the Aviation Safety Reporting System (ASRS) database that indicates the significance of task management. In this incident, pilots of an airliner were communicating with passengers as well as making in-cockpit communications. Meanwhile, the autopilot's target altitude changed from 35K to 33K without any interaction. By the time the pilots recognized this, the altitude was 400 feet less than the cleared altitude, fortunately before any accident.

Iani and Wickens (2004) suggested a task hierarchy to ease the allocation of attention strategy of pilots under such circumstances. This hierarchy is "aviate, navigate, communicate and system management (ANCS)" (p. 2).

The previously mentioned ASRS report is a good example of why task management is highly significant in advanced cockpit aircraft. Actual aviation is always the highest priority task when flying, followed in succession by the other

tasks. The incident cited above is another example of automation complacency. Over time, pilots become too dependent on automation, as well as being over confident about the trustworthiness of the automated systems. These kinds of mistakes may be critical and safety threatening, especially under high workload situations, in which it might take more time to recognize an automation error, if it could be recognized at all.

Task management is defined by Funk, Suroteguh, Wilson, and Lyall (1998) as “the process by which the operators of complex systems prioritize and perform the multiple, concurrent tasks that compete for their attention” (para. 4). In this process, the operator is supposed to decide which task to attend to before all the other tasks, a phenomenon based on allocation of attention.

Based upon these incident reports, in Figure 2 the authors express the significance of the number of incidents in advanced cockpit aircrafts. One thing important to note here is the decrease in the number of incidents through the years. Funk, Suroteguh, Wilson, and Lyall (1998) also suggested that it could be concluded that over time pilots became more used to automation.

Submission Period	Task Prioritization Error Frequency		Total Errors by Submission Period
	Advanced Technology	Traditional Technology	
1988-1989	13	7	20
1990-1991	11	5	16
1992-1993	4	3	7
<b>Total Errors by Aircraft Technology</b>	<b>28</b>	<b>15</b>	

Figure 2. Reported task prioritization incidents between given time periods  
(From: Funk, Suroteguh, Wilson, and Lyall, 1998, p. 4)

In Figure 3, Funk, Suroteguh, Wilson, and Lyall (1998) summarized the factors that could be important in task management performance. The numbers under the references block indicate the number of studies in the literature that has suggested the related line as an important factor in task management performance. The ones marked with “\*” on the other hand, are the suggested factors by the researchers, which were not previously identified in the literature.

<b>Factors</b>	<b>References</b>
advance knowledge of upcoming tasks	[10]
discriminability of task-related stimuli	[10]
differences in level of effort required to process task-related stimuli	[10]
temporal proximity of task-related stimuli	[10]
task importance: aviate > navigate > communication > manage systems	[13]
perceived urgency of task (time remaining vs. time to complete)	*
task difficulty	*
(automation) task proficiency	*
task recency	*
task momentum: tendency to continue to perform the current task	[13]
task proximity to completion	*
amount of effort already invested in tasks	*
perceived task status (satisfactory, unsatisfactory)	*

Figure 3. Factors affecting task prioritization (From: Funk et al., 1998, p. 6)

Iani and Wickens (2004) found that task switching time was directly related to salience of the cue. They suggested that: “people tend to be more proactive in task management when workload is low and more reactive when workload becomes high” (p. 2).

Iani and Wickens (2004) stated that even if the task prioritization order should follow ANCS hierarchy in an effort to allocate the attention ideally, this is not always the pattern that performers follow. They noted there were accidents because of devoting attention to one task while a higher priority task was neglected. Iani and Wickens also referred to an accident as an example of this kind of neglect, when the pilots of an airliner were distracted by a landing gear indicator failure. Pilots devoted their attention to this malfunction, resulting in the neglect of aircraft control, and failure to recognize the descent of aircraft. Thus, the airliner crashed with the death of all on board.

Freed (2000) focused on the task prioritization computation of agents, and suggested a heuristic prioritization, when all other factors were equal, with the following order:

First is urgency, which is the time period until the deadline of the task, suggesting completion of the nearer deadline first. Second is importance, which depicts the consequences of missing the deadline of a task, suggesting completion of the most important deadline first.

The third factor—duration—is important for two reasons. First, the task duration might affect the completion of other tasks before their deadline, and second, depending on the duration of tasks and given deadlines, the task prioritization order would change, therefore suggesting completion of the briefer task first.

The last place in this heuristic goes to interruption cost, which depicts the attention switching costs from one task to another, suggesting completing an ongoing activity rather than switching to another (Freed, 2000).

Iani and Wickens (2004) gave the factors affecting task prioritization in the following order: task complexity, attentional tunneling, task importance, and physical salience. They state that switching attention to new tasks depends on the urgency of the ongoing task, and the attentional resources it allocates. While there is an attentionally demanding ongoing task, there will be fewer attentional

resources to attend to the other tasks. At this point, attentional tunneling comes on the table, because it is not always the case that the operators use their attentional resources on the more complex tasks, instead attending to less complex but more urgent ones. Therefore, Iani and Wickens concluded that the urgency of the ongoing task, not its complexity, is the most significant factor when it comes to switching attention between concurrent tasks. Independent from urgency and complexity there is task importance. Operators should compare the importance of tasks while allocating their attentional resources, suggest the authors. However, they suggest the physical salience of the task here to explain the fact that tasks are not always initiated due to their importance. They pointed out evidence that memorial or less salient reminders are less likely to initiate an attentional switch than the salient reminders. They also pointed to evidence that auditory salience is more effective in switching attention to new tasks than is visual salience, and the switching time of higher priority interrupting tasks was much faster than the lower priority ones. Their findings support this evidence, and expand it by stating that auditory modality does not deprive high priority flight tasks from attentional resources because it works parallel to the visual flight parameters.

On the other hand, Damos and Tabachnick (2001) found that task duration and structure had significance on interruption of the ongoing tasks. It was seen that ongoing tasks that cannot be divided into sub-tasks and are relatively shorter in duration were not likely to be interrupted. They also stated that something which occurs frequently would indicate less time and safety critical information, thus would be most likely to be assessed as too low priority a task to interrupt the ongoing one.

Prospective memory was explained by Berg (2002) as the memory where the intentions to take certain acts are kept for the future. It is expressed that acting upon remembering is significant, rather than just remembering those intentions.

In a recent study, Dismukes (2006) analyzed aviation accidents where crew error was the major component of the reason. He found out that neglecting the regular operational sequences was a significant factor of crew related errors. To find out the underlying reasons for such errors from experienced pilots who have done the same operational procedures countless times, he ran a study and argued that prospective memory along with multi-task management constituted a reason for human error.

Dismukes (2006) characterized prospective memory by the following traits: the intention to take an action in the future when conditions permit, time between intention and its performance (which is allocated with other tasks), and the absence of an indication to remind it to the performer explicitly. He stated that the crucial issue is to retrieve these intentions from the memory when the circumstances permit, but not to keep them in the memory. He suggested that prospective memory plays a significant role in the following task situations in the cockpit: episodic tasks, habitual tasks, atypical actions substituted for habitual actions, interrupted tasks, and interleaving tasks and monitoring. He stated that, unlike habitual tasks, episodic tasks have to be remembered to be performed. Dismukes added that in the information rich environment of cockpits, the pilot's attention might be allocated to some other cues rather than the ones that would help to retrieve episodic tasks. Habitual tasks, on the other hand, hold a risk of omitting some important steps, especially when the sequence of operations is changed for some reason. Another phenomenon related to habitual tasks is when the pilots need to substitute their habitual procedures under some particular circumstances. Dismukes stated that pilots might attend to their habitual procedures rather than the substituted one. He pointed out a common error where pilots do not return from their interrupted tasks after accomplishing the interrupting task. Findings of his study showed that the reason for this behavior was not having explicit cues in the perceptually rich environment of the cockpit. Another reason was the oncoming task demands right after the end of the interrupting task, which prevented the participants from comprehending the

situation and retrieving their prior intention from the memory to return to the interrupted task. Another task demand that might cause prospective memory retrieval issues is when the pilot needs to shift attention to monitor another task, while performing an ongoing task. Dismukes (2006) stated that even if their consequences might be significant, monitoring low probability events might be difficult because a human has a tendency to allocate his attention to the sources where he can get more information.

Hancock, Williams and Manning (1995) stated that human performance is not a linear phenomenon that works directly proportional to the given task demand. The authors mentioned that automation has changed the pilot's role from operator to system manager. They referred to literature about two contrary opinions about the task demand, workload and human performance relationship. The first opinion claimed that workload is directly related to the task demand characteristics under circumstances where attention is directed to the source for prolonged periods. On the other hand, it was claimed that workload and task demand are separate phenomena, and under some circumstances, workload and human performance are directly proportional to another, where human performance increase is observed as workload increased.

Considering this background, Hancock and his colleagues made a study to point out the relationship of task demand, workload and performance. Their findings indicated that the perceived workload of a performer is related to the level of task demand he was subject to until that time (e.g., pilots who transitioned from a relatively higher task-intensive platform perceived the workload as low, while pilots transitioning from low task-intensive cockpits perceived the given workload as high). Therefore, the authors suggested that to better assess the current workload level, task/mission history has to be taken into account. This perception of relative workload leads to the conclusion that pilots coming from high to low task-intensive environments should perform better and vice versa. The initial reflex is to associate high workload with poor performance, while linking low workload and good performance. However, the authors

observed that transitioning from a higher task-intensive cockpit to a lower task-intensive one did not produce higher human performance, but lower. The authors suggested that workload analyses provide a window of efficiency which may enable proactive behaviors in cockpits by potentially providing information before the fact happens. They suspected that the reason for uncertainty in correlation is nonlinear human characteristic, because of some observations where performance increased while the tasks became harder. They commented on the promising findings where performance and workload appear to be associated in monitoring tasks, which constitute an increasing percentage of the tasks to be done in each new cockpit design.

In a study to examine mental workload and situational awareness, Alexander and Nygren (2000) stated that mental workload is important in assessing systems, but that when assessing the quality of information that the operator is using, situational awareness should be also considered. In their experiment, Alexander and Nygren compared two different cockpit interfaces: a conventional one, and a virtually augmented cockpit with advanced displays. They found that mental workload was lower in the virtually augmented cockpit than in the conventional one.

Alexander and Nygren also stated that having high situational awareness enables pilots to function more effectively and with more time awareness. They mentioned that even if situational awareness and mental workload are inter-related, they are considered to be independent elements, referring to the findings where mental workload ratings increased with the increase in task demands while situational awareness ratings did not change. However, their findings indicated a relationship between mental workload and situational awareness. They observed that changes in the experimental set up which caused mental workload increase resulted in a decrease in situational awareness.

Wilson (2002) examined pilot workload using measures such as heart rate, eye blinking rate and the electroencephalographs (EEG) of pilots. He stated that increasing heart rate would indicate increasing mental workload, and that

decreasing blink rate would indicate increasing visual demands. He noted that these psycho-physiological measures changed more than the other phases of flight at takeoff and landing phases. He also showed that when pilots flew similar maneuvers to the ones they did before, their workload ratings were lower than when they conducted less familiar maneuvers.

#### **4. Auditory and Visual Resource Considerations**

In a current study, Lee, Lee and Boyle (2007) examined the effects of voice interactions of drivers to assess the effect on their attentional guidance. They predicted that voice interactions with in-vehicle systems, while enabling them to keep their visual focus on the road, would cause additional cognitive load. Therefore, this load would cause delays in their responses to regular events such as braking and showing reaction to traffic lights, when responding verbally to auditory messages rather than just listening to them. In their experiment, the main task of their participants was to follow a frequently braking lead car at a certain distance. Concurrently, the participants were supposed to follow and remember signs, pedestrians and various similar targets in the scene, and listen to an auditory message, then respond to questions about this message. This experimental design composed a complex dynamic situation containing many tasks required to be done more or less concurrently.

The findings of the study supported their predictions. Lee and her colleagues found that drivers showed slower reactions under dual-tasking conditions, where both tasks required a response from driver. This finding, however, was mostly the result of attentional distraction, because the drivers had to respond to asked questions, but not because of the additional information given by the auditory message.

Similar to this finding, Damos and Tabachnick (2001) reported that when the ongoing task in the cockpit was auditory, pilots reacted slower to the interrupting tasks.

The findings of Iani and Wickens (2004) established the basis for these suggestions, where they stated that the auditory modality, in fact, is a factor that supports the parallel processing of visual control sources.

According to Wickens and Ververs (1998) the main reason for putting HUDs in cockpits is to present necessary information to the pilot on one source, so that he can save his attentional sources for higher priority tasks rather than using them to re-accommodate while switching from one display to another to extract the necessary information. Thus, it is critical to understand the way attention is modulated.

Wickens and Ververs (1998) pointed out evidence that a HUD creates attentional narrowing, especially under high workload situations, thus avoiding the assessment of presented data on the HUD by the pilot. They referred to a military report to indicate the possible threats of attentional narrowing caused by HUDs. In this incident, the pilot failed to notice the barrier on the runway due to overloaded symbology on the HUD, in addition to the excessive brightness, resulting in an accident.

Wickens et al. (2004) suggested that one significant issue is “to evaluate the general tradeoff between the scanning costs of a separated display, and the clutter costs of a more integrated display” (p. 5). While the clutter costs for target detection have been observed before, they found evidence that symbology clutter even degrades the detection rate of expected targets. However, in some cases, the benefits of some sources of clutter were great enough to dominate their costs, because they reduced the workload.

The data in Wickens and colleagues' study revealed that pilots use the synthetic display to extract the attitude information even if they can see the horizon in IMC. This attentional preference establishes a significant threat to pilots, especially when there is information outside which is not presented on the synthetic display. This finding supports the automation complacency risk suggested by Wickens (2000).

Wickens and Ververs (1998) referred to basic attention and aviation literature to point out the findings that show the negative effect on attention of having unnecessary symbology and visual data. They state that it is highly significant to determine which data is required within the context of any given flight phase, following which the rest should be cleared accordingly. Their results indicated that high clutter disrupts the target detection performance both in near and far domains.

The presence of more symbology than is required for the current task was pointed out to be a factor making the attentional switching harder between near and far domains, due to increased clutter on the display, thus resulting in attentional capture or tunneling.

Yeh, Wickens and Seagull (1999) pointed out that the scanning cost of head-up display clutter is less than the scanning costs of head-down instruments. However, they also stated that the cost of scanning of head-up displays increases significantly with the increasing symbology on these displays intended to present more information to the pilot. They claimed that previous research has proved that pilots are more vulnerable to miss the information in the real world and make errors with a cluttered display in their field of view because of impaired vision due to increased symbology.

Wickens and Ververs (1998) analyzed the scanning vs. clutter costs, and their influence on near and far domain target detection. They reported that the reduction in the costs of attention switching between the head-down displays and the scanning cost outweigh the clutter cost of HUD in detecting environmental targets. HUD decreased the detection time of far domain targets significantly. On the other hand, clutter adversely affected the near domain target detection performance when it came to recognizing the change on the HUD symbology, as well as far domain.

Prinzel and Risser (2004) commented that being attentionally captured because of the salience of the near domain cues, pilots experience difficulty in

switching their attention between domains; thus, they cannot process two sources of information at the same time. They pointed out pilot reports, where several of them admitted that they sometimes find themselves being so fixated on near domain cues that they are totally unaware of anything else.

Wickens and Ververs (1998) found that pilots prefer to use the environmental sources to extract attitude information, which would explain why they do not keep their eyes down on the flight instruments as much as they might. These results favor the use of HUD over head-down instruments, of course.

Yeh et al. (1999) found out that cuing symbology on HMD was useful for expected targets and helped subjects to point out them out, while distracting them from unexpected ones. They pointed to evidence from an air-to-ground mission experiment indicating that cuing symbology resulted in erroneous decisions, making pilots target non-target locations.

This result is compatible with the habits of pilots using HUD. In an air-to-ground attack, pilots continuously track the approximate target location while pulling the aircraft to that direction to put the target in the field of view of HUD. When the HUD field of view covers the area, the cuing symbology is seen overlaying on the target. This order enables pilots to avoid computer generated error, as well as human error, because it gives opportunity to double check and assess whether the correct target has been acquired. Therefore, it is also fair to claim that pilots using HMD are more susceptible to targeting errors unless their systems work perfectly, because the continuous symbology in the field of view is going to discourage them from focusing their attention on the far domain.

Yeh et al. (1999) stated that when there is a contradiction between the information acquired from the real world and the information from computer generated symbology (automation); the pilots' decisions were to trust in the automation-based information. Their results support this claim by stating that the

presence of cuing information might draw attention to a certain area, thus withdrawing attention from surrounding areas.

Yeh and colleagues also suggested that cuing symbology on HMD's could increase attentional tunneling, after their experiment about using an HMD and computer-generated fault imagery for aircraft inspection. They also stated that "the presence of cuing may result in an inappropriate allocation of attention: an overreliance on an automation-based cue" (p. 539-540). Further, they suggested that as the amount of information presented in the field of view of the pilot increases, the target detection rate decreases because of the allocation of the pilot's attention to the near domain.

Johnson, Wiegmann and Wickens (2005) found that as the attention allocated to a certain area of interest increases, the task performance of the pilots, which require other areas of interest, decreased proportionally because the pilots could not allocate the necessary amount of attention to these sources.

Johnson, Wiegmann and Wickens also stated that the performance of pilots on certain tasks that are based on visual scanning is also negatively affected by hi-tech cockpit displays, as is the visual scanning itself. They suggested that if pilots' visual scanning is interrupted by the in-cockpit displays, thus drawing attention into the cockpit and away from the world outside, their assessment on weather conditions will become weaker over time.

Wickens (2002) indicated that salient display cues are beneficial to remind pilots of the tasks to be done, thus mentioning the importance of allocation of attention to better task management. Connected to this statement, Wickens criticized the task management strategies that direct the pilot's attention to a certain direction to inform him about the flight data. He stressed the importance of training in task management by defining what makes a pilot a better task manager, and stated that the key to becoming a better pilot is the ability to share the attentional sources between the outside world and the informative cockpit displays.

Bohnen and De Reus (2004) stated that one of the most significant indicators of mental workload is the visual allocation of attention, and used it as a manipulator to find out the effect of number of displays on pilot workload. Their findings indicated that as the number of displays associated with concurrent tasks increased, pilots could not maintain the same flight performance because of limited attentional sources. However, they also found that increasing the number of displays did not bring additional mental load, thus pointing out the visual allocation of attention as the reason for performance decrease. On the other hand, they observed that pilots developed new strategies to manage attentional sources and maximize flight performance while doing the other concurrent tasks. Thus, the authors expressed the importance of considering pilots' attentional management strategies next to visual allocation of attention while predicting the workload.

Horrey, Wickens and Consalus (2006) stated that as more technologies are implemented in cars, a safety concern arises because these new implementations are going to compete for the limited visual and attentional resources of drivers, thus reducing the resources allocated for the primary task, driving. They claimed that the eye is kind of a "single-server queue" and visual scanning is the server of this queue.

Horrey et al. (2006) expressed the importance of expectance and information bandwidth by stating that performers become more likely to monitor the displays/information sources where they find relevant information more frequently than others. They showed evidence of this phenomenon in that the experienced drivers were observed to have more extensive visual scanning while novice drivers became fixated on cars around them during a task where they had to track their lane in a demanding road environment. This observation, the authors suggested, indicates that experienced drivers have a better idea of where to expect and extract the relevant information than do novice ones.

Horrey and his colleagues suggested that a scanning pattern should optimize the cost-benefit effectiveness, where it increases the benefits of scanning while decreasing the costs of missing information.

In an experiment, Horrey and his colleagues (2006) used the SEEV (Salience/Effort/Expectancy/Valuable) model where they intended to point out the influence of in-vehicle tasks on driving performance and visual scanning patterns. They explained the parameters of this model as follows: salience is the obviousness of information on an information source, effort is the visual angle difference between informational sources, expectancy is a combination of bandwidth and value of the information on a display which indicates the task relevance and importance of information for the given task, and value is the importance of that information compared to the others. The authors pointed out a weakness of the SEEV model by stating it is built on the “momentary allocation of focal (foveal) vision” while there are various tasks where necessary information can be extracted through ambient vision (p. 68). This evidence indicates that performers do not necessarily need to fixate their attention on focal vision for all the information sources. Focal vision is said to be linked directly to eye movements, and used for visual search and tasks such as reading, which require “high visual acuity,” while ambient vision is mostly used for spatial orientation, and postural control in locomotion.

Prinzel and RIsser (2004) stated that a large part of the world in humans’ vision is continuously monitored by ambient vision, and only a smaller part by foveal vision. They stated that these two vision systems work in a parallel fashion, without competing for the same attentional source.

Horrey et al. (2006) showed evidence that experienced drivers can use their ambient vision more effectively than novice ones for lane tracking, even without moving their eyes to direct their attention on the road.

The findings of Horrey and his colleagues showed an increase in performance proportional to the increase in allocation of focal visual sources that

was related to the increase in value of that particular task. Therefore, it has been seen that as the priority of that task increases, more attention is directed to that task, which results in better performance. Their findings also indicated that as the complexity of in-vehicle systems and their bandwidth increases, the lane-keeping performance decreases due to switching attention from the road to in-vehicle displays. Drivers' response time to safety critical situations, which is dictated by the time for the eyes to move from down inside the vehicle to the road, also increased, pointing out the role of focal vision. However, the correlation between focal vision and hazard reaction times is not that strong, suggesting that ambient vision is also used for hazard detection and reaction, though still requiring focal vision to correctly identify and react. This study examined only one-task conditions. No multi-task performance was examined, so the increase in task performance when the allocation of attention to one source might not prove to be beneficial under high workload conditions. However, the findings are significant to support the importance of task prioritization in allocating the attentional resources to the required task.

Horrey and his colleagues' (2006) results showed that increasing the frequency or complexity of in-vehicle systems influenced the driving performance more than the manipulation of outside factors, indicating the importance of allocation of focal vision attention.

## **5. Decision Making Considerations**

Decision-making often becomes very demanding in the cockpits. In order to mitigate the problems, it is crucial to understand the decision-making process, and better decision-making practices, via the literature.

Doherty (2001) mentioned Klein's "recognition-primed decision making model (RPD)" (p. 15). The model says that experienced pilots relate their current situations to their stored situations from their experiences and make correct decisions easily. Considering the capabilities of JSF, this kind of decision-making ability will be crucial. In high-risk, limited time situations and with lots of available

information via the displays, it will be very important to make the correct decisions quickly. As Doherty mentions, the required experience for RPD can be built in various ways such as real or training missions and training systems.

Similarly, Spencer (2000) discussed that in many situations, the experts make quick decisions depending on their experience. Over time and training, they build a repository for many situations, and if a critical situation requires a very quick reaction, they retrieve the closest match and decide their next move.

The multirole capability, increased number of complicated sensors, and sophisticated autopilot are the main features of JSF that create differences from previous fighters. If one also considers the missions that JSF will perform in the future, it becomes obvious that the pilots will be under high workloads in limited time frames while performing their tasks. Thus, properly trained automated responses, like RPD, will become more crucial.

A typical mission scenario example will be very explanatory in terms of mission nature: during composite air operations (COMAO), where multiple Air-to-Air, Air-to-Ground, friendly and hostile assets are in the battle area, it will be highly likely that a JSF pilot will be looking at a complicated picture with a lot of information in the cockpit. Considering the time constraints, and other stressors, it is easy to conclude that the pilot's ability to look at the displays, filter the data, and evaluate it for a quick and correct decision will be very challenging. And from the beginning of their exposure to JSF, the pilots will have access to all of these sources of information. Considering the number and the complexity of the systems, a considerable amount of training will be needed to achieve the ability of accomplishing the aforementioned tasks.

## **6. Models to Predict Allocation of Attention**

Even if the prediction of attention allocation is beyond the scope of the current study, the authors of this thesis believe that briefly mentioning some models can help to understand how the process of human attention is captured.

Fleetwood and Byrne (2004) analyzed three models of visual attention allocation to point out the attentional patterns and where the performer is going to direct his attention next. They focused on the following factors to determine to what extent they influence the attentional patterns of the performers: the frequency of information generation on the monitored display, the probability of critical information coming up while monitoring another display, the cost of missing/detecting critical information, and the cost of monitoring.

The first model they analyzed was the Senders model. This model concentrates on the frequency of information generation (this factor also is called the bandwidth of related instrument/display) and the alarm frequency of this instrument. However, Fleetwood and Byrne expected this model to predict less accurately when under complex task conditions because only the bandwidth can be manipulated. This expectation might indicate that this model is less likely to be used in aviation, where the complexity increases due to higher workload.

The second model Fleetwood and Byrne examined is the SEEV model. The name of the model stands for Saliency, Expectancy, Expectancy and Value, which constitute the factors that this model considers to influence the allocation of attention. Authors expect a high and relatively accurate prediction rate from this model, unless its results are extrapolated for more specific ones. Fleetwood and Byrne stated that the information extracted from a source, the effort to monitor that source and the effort to switch attention from one information source to another are the factors considered by the Information Foraging model. They said that SEEV and Information Foraging models predict that the sampling frequency of an information source is relevant to the value of the information extracted from that source.

## **7. FAA Research about Flight Training**

The main consequences of modern aircraft are the enhanced capabilities, increased number of sensors, and automation. A very important and useful set of research related to the human factors concerns in modern cockpits is the

research conducted by the FAA about general aviation. The research began approximately in 2003 with a final report analyzing the mishaps of modern general aviation aircraft, and continued to evaluate almost to the present day. Another important aspect of the research is the solutions proposed about the training.

The first related study is the final report by Fiduccia et al. (2003). Their study is based on 11 accidents, all of which had issues related to “Technologically Advanced Aircraft” (TAA). Their definition of TAA is:

- a. IFR-certified GPS navigation equipment (navigator) with moving map; or
- b. A multi-function display (MFD) with weather, traffic or terrain graphics; and
- c. An integrated autopilot. (p. 9)

This definition has similar parts to modern fighter jets, in terms of the MFDs, GPS and autopilot. It is legitimate to see their study as a case study on the accidents by Subject Matter Experts. And as an important conclusion, Fiduccia and his colleagues claim that the traditional flight training did not address the use of relatively modern technological systems, and that a study on how to address all required issues of the new technology needed to be conducted. This study established the basis for the following related studies that sought solutions to this common training concern.

French, Blickensderfer, Ayers and Connolly (2005) conducted one of the follow-on studies in order to study the differences between the “maneuvers based training (MBT)” and the “scenario-based training (SBT)” (p. 3). The MBT is generally the approach of the traditional instrument training used so far, and the SBT was the proposed solution by the TAA research team after conducting research on the accidents in TAAs. They explain that SBT is a student centered training approach in which the students declare their problematic areas and build appropriate and realistic training scenarios to improve them. After this process, it is the instructor’s responsibility to come up with appropriate “performance

measures.” Then, the instructor decides the success of the trainee using those performance measures and gives feedback. The main point of SBT is that “...the scenario is the curriculum” (p. 6). French and colleagues also explain the traditional training approach as based on MBT. The repetition of the required maneuvers makes the trainees proficient. The maneuvers are not implemented to scenarios, and the student only follows the syllabus, but this does not contribute to the flow of his training with deciding what to practice in which realistic scenario.

French and colleagues conducted their study with 27 participants who were not experienced in TAA. Those participants ran through a pretest, received 8 hours of training with either MBT or SBT, and then completed another test thereafter. They divided the phases of flight into eight categories and graded them separately with a “blind rater.” Additionally, they also used subjective surveys in order to learn personal opinions and get deeper insight. Their results revealed that the trainees with SBT received higher grades than MBT trainees in five out of eight categories with a statistical significance, and in the remaining categories their grades were equal. The authors also add: “Further, the SBT group demonstrated a tendency to report reduced workload and an improvement in self efficacy and situational awareness compared to MBT” (French et al., 2005, p. 3).

Robertson, Petros, Schumacher, McHorse and Ulrich conducted one of the FAA sponsored studies in 2006. The purpose of the study was to measure the differences between the “problem-based learning” studied by the FITS and the traditional training approaches. In PBL, the scenarios should be prepared such that they force the trainees to face more challenging and harder cognitive processes, and to evaluate and compare more than one alternative during the decision making process. They reported that FAA has accepted the shortcomings of the current training approaches in “atypical” conditions. Regardless of whether a situation was normal or abnormal, it was designated as typical when the standard response to that situation was covered in the training.

They defined the “atypical” situations or hard conditions as those with many alternative solutions that were complex, and which were not covered during standard training (Robertson, Petros, Schumacher, McHorse, & Ulrich, 2006, p. 2).

To teach the required skills to pilots for giving them the ability to make the proper decisions during the atypical conditions, it is necessary to address the complex or advanced decision making skills during the training. And they reported that the current training systems do not address this issue; that was one of the objectives of their study to evaluate “Higher Order Thinking Skills” in their training system (Robertson et al., 2006, p. 3).

Robertson and colleagues conducted an experiment using a simulation program in a personal computer. The three groups were used for a FITS preferred PBL approach, or the traditional training approach and self study group. Each group was given a test before they began their training with a TAA aircraft simulation, went through their training and at the end took a posttest of their new TAA aircraft. Their participants were college students who had private pilot license and were certified to fly in Instrument Flight Conditions. The traditional and self-study groups were given traditional training during the ground lessons, briefings and flight lessons. They were asked multiple choice or straightforward questions requiring direct answers. The PBL group was given questions via the scenarios that required the students to do further research with their documents. Also, the answers to these scenario-based questions were not as straightforward as the other groups’ questions; rather, they necessitated more intensive mental efforts (Robertson et al., 2006).

Both subjective and objective measurements were used. The simulation game had the feature of data collection and saving. That feature was used to get the objective measurements about the parameters of interest such as altitude, airspeed, etc. SA was measured by the questions asked by the researchers, while they stopped the simulation. “Aeronautical Decision Making” was measured subjectively by the observing researchers, and objectively by examinations about

the HOTS. They reported that the participants with PBL performed significantly better under complex conditions, and added “The findings also reflected improvements in the indicators of aeronautical decision-making (pilot judgment) and a reduction in the number of mistakes made by the pilot” (Robertson et al., 2006, p. 60).

Dornan, Beckman, Gossett and Craig (2007) are the last researchers of the FAA research. One of the recommendations of their report was adding “consequences” to scenario-based trainings. They claimed that without any consequence, the scenario-based training would not be fully useful, because to come up with a solution will require less effort. But when adding serious consequences to the scenario, the trainees will be forced to process more information, and use more cognitive resources; thus, the end result of the training will be more beneficial. The example they had for such an input was injecting a “...transplant organ to the destination airport” in a possible divert decision scenario. Apparently after going through that kind of hard, challenging decision, the trainees will gain more than without any consequence injected training (p. 3).

Another method of exploring the proper decision-making skills is looking at the experts. Many studies have been conducted for that purpose, and point out similar phenomenon. Spencer (2000) discussed this common finding that in many situations, the experts make quick decisions depending on their experience. Over time and training, they build a repository for many situations, and if a critical situation requires a very quick reaction, they retrieve the closest match and decide their next move.

The cockpit automation, load on visual resource, informational overload, cognitive resources, attentional allocation, training considerations and many other topics covered in this chapter provide a background on all of the required aspects of human factors concerns in modern glass cockpit aircraft. The following chapters benefit from the relevant studies mentioned in this chapter, both in problem identification and training recommendation purposes.

## **C. THE IMPORTANT FEATURES OF JSF RELEVANT TO HUMAN FACTORS**

One of the important objectives of this thesis lies in understanding the features and capabilities of JSF. The authors believe that JSF has many new capabilities and systems leading to new required skills and human factors concerns. In this chapter, these topics as well as the differences among fighter cockpits are provided. First, the features and major systems of JSF are introduced from unclassified documents, and then possible human factors concerns are predicted from the literature and the operational experience of the authors.

### **1. General Features and Systems of JSF**

JSF is intended to be a "... multi-branch, multinational, supersonic fighter," which is planned to replace most of the current generations of aircraft in the contributing countries' air force inventories. With its advanced features and three variations for different platforms, it offers multi-role capabilities. Fusing the data from many sensors onboard the aircraft is claimed to be the major strength of its design (Jensen, 2005, para. 2). Even if the flight performance, maneuverability and G-performance are not necessarily superior to the previous generations, the systems presented with this aircraft offer new capabilities and operational concepts. Next to the improvements on already existing systems, some highly intuitive systems are introduced to the aviation community for the first time, such as the electro-optical distributed aperture system (DAS). Even if there are many other points to consider assessing JSF, its capabilities, and pilot vehicle interface, the authors think the following systems are more likely to affect mission effectiveness.

The most striking difference and innovation of the JSF cockpit is the 8"x20" liquid crystal display screen right in the middle of the forward panel (Figure 4). Almost all of the information from the sensors and systems are presented to the pilot via this display, which can be modified by touch screen

buttons to reach and modify any desired system data. This display will be the major PVI system between the pilot and aircraft.



Figure 4. JSF cockpit with LCD display suite (From: briefing received from PVI Team at Lockheed Martin, Fort Worth, TX)

The forest of toggle switches in previous fighter cockpits has been wiped clean from the F-35's interior landscape, with most of their functions moved to the touch screen. A few switches still sprout here and there, but the overall cockpit ambience is one of simplicity and calm, almost to the point of aeronautical *feng shui*. (Kent, 2006, para. 3)

These features give the impression that it will be very intuitive and easy to operate the systems of JSF.

After providing a general picture about the capabilities and cockpit design of the JSF above, it will be necessary to focus on the individual systems. The

following systems and their features do not cover all of the systems and capabilities of JSF, but are thought to be the important ones relevant to the scope of this thesis (related to human factors concerns). Limited information can be found online and in some published resources. But because JSF is still under development, there is much restricted information due to security concerns, and the following information is cited directly from unclassified sources online. For further information, the readers can follow the references.

## **2. Radar**

The AN/APG-81 fire control radar, developed by Northrop Grumman, has the following general features:

- Terrain mapping with high resolution, able to cover an area three to four times wider than existing radars. This feature enables pilots to have better assessment of the area of interest by giving high resolution and wider field of view (Jensen, 2005). This feature might also introduce attentional tunneling issues along with itself because pilots might fixate their attention on this display to search and acquire the target.
- Provides both air-to-air and air-to-ground target information at the same time. This is a significant capability to provide the pilot a better situational awareness in a multi-threat environment, where he can assess all the given parameters and make quicker and more accurate decisions (Jensen, 2005). This capability is not present in current generation fighters. However, it may present a challenge to informational management, where the pilot should be able to filter the unnecessary data and focus on the required ones. Pilots, apparently, are required to manage their mental resources more effectively in order to cope with ample data and make better decisions.
- It can be slewed to any other sensor's field of view, whether the other sensor is onboard or off board (Jensen, 2005). This feature amplifies the

situational awareness and the coordination among friendly assets; however, given information does not allow any further assessment in terms of human factors concerns.

### **3. Electro-optical Targeting System (EOTS)**

Along with the AN/APG-81 radar, the EOTS is one of the major sensors of JSF.

- It consists of non-active sensors operating both during night and day; enemies are not able to intercept any signals because it doesn't radiate any signal.
- It provides very detailed IR images to the pilots, and is said to be an additional way of acquiring and analyzing targets in addition to the radar. The pilots will be able to acquire the targets beyond visual ranges, and sync the radar with EOTS, in order to examine the targets in more detail.
- For Air-to-Air purposes, it has an Infrared Search and Tracking System (IRSTS), and for Air-to-Ground purposes a Forward Looking Infrared Radar (FLIR). Any off-board system can target laser to target, and those lasers can be locked by a tracker in JSF (Jensen, 2005).

Apparently, the pilots will focus on both radar and EOTS in many task situations. Focus and attentional distribution as well as having robust mental models on both systems will be crucial with such advanced systems.

### **4. Distributed Aperture System (DAS)**

The electro-optical distributed aperture system (DAS) has the following features:

- Consists of six IR cameras.
- Provides vision through the body of the aircraft.
- Works in collaboration with the helmet mounted display (HMD) to relay a continuous 360 degrees of passive environmental information to pilot.

- Gives the pilot “missile approach warning, countermeasures deployment, passive air-to-air radar, off-axis targeting for air-to-air missiles, and wide field-of-view day/night pilot vision” (Jensen, 2005, para. 20)
- The integrated data from all cameras can be superimposed over a tactical display which can be reached via data link from ground units or another flying asset (Jensen, 2005).

The DAS intends to increase the situational awareness of the pilot while not overloading him with excess information. The system itself, along with its ability to work in collaboration with data linked tactical pictures, is intended to ease the pilot’s workload of adapting himself to the tactical arena, comprehending, deciding and taking action (Jensen, 2005).

However, being such a new system, these authors think that it will take some time and operational experience to be thoroughly assessed by means of flight safety in certain conditions. Previous studies done on visual attention allocation are helpful to consider the possible attentional tunneling issues associated with this system and its presentation on HMD. However, future research should be encouraged by air forces operating this aircraft, not only depending on simulator experience but also pilot feedback from real operational missions in various weather and mission scenarios. A question that arises is pilot disorientation. What kinds of effects will the DAS cause to pilots after “looking through” the fuselage and returning back to normal vision in bad weather conditions? These types of concerns should be considered during training to cope with any possible problems. Another issue is the balance between the capabilities of the aircraft and the pilots. Apparently, the aircraft has the potential to dominate the pilot with ample data and many other capabilities. But how to raise pilots’ capabilities to a point that they can fully benefit from the data safely and efficiently without fixating or becoming disoriented seems to be a challenge during training.

## **5. Communication/Navigation/Identification (CNI) and Other Capabilities**

The CNI system will be approximately similar to the most modern current generations, but the officials report that it will be more tailored to fit in “network centric warfare” (Jensen, 2005). The system is also reported “... to provide such functions as beyond-visual-range identification friend or foe, secure voice communications, caution and warning, intercom, and intraflight information sharing among multiple aircraft via high-speed broadband data link” (Jensen, 2005, para. 29). JSF will also have other current data link capabilities to share information (Jensen, 2005). The aforementioned capabilities will take JSF one step further in terms of information dominance, and common tactical picture; thus, ability to filter and evaluate the data, and make proper decisions, will probably be an important training requirement with all of the on- and off-board data sources. The design of JSF will probably achieve the point that the pilots are no longer challenged to collect information, but to use that vast amount of data.

Another innovative application in the cockpit is reported to be the 3-D sound system. “Three-dimensional audio algorithms, to direct appropriate audible cues 360 degrees around the pilot are expected to be part of the CNI suite's future growth” (Jensen, 2005, para. 33). This feature will apparently reduce the visual workload in some cases, and increase SA easily during high workload situations. Distribution of signals or information to visual or auditory displays (or both), establishing proper standard operational procedures, and training for pilots will be necessary to enable them to benefit from this new capability.

### **D. POTENTIAL RESEARCH CONCERNS ABOUT HUMAN FACTORS IN JSF**

Based on the research literature review and considering the features of JSF, the following questions are the major areas of research this thesis tries to identify:

Concern 1. What are the potential areas that could cause Negative Transfer of Training (NTT) problems during transition period?

Concern 2. How will the pilots filter the data and focus only to the required ones?

Concern 3. What kind of new skills will be needed for JSF?

Concern 4. What kind of concerns can pose problems about pilot-autopilot interaction in JSF?

Concern 5. Which systems of JSF are going to cause problems to the pilots, and thus need to be addressed carefully during training?

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### **III. METHODOLOGY**

#### **A. INITIAL SURVEY AND INTERVIEWS**

The main objective of this thesis is to identify and point out the critical components in transition, to follow the phases of JSF in terms of Human Factors considerations, and then to discuss the possible ways to avoid any problems beforehand.

The initial reflex was to focus on the accidents and mishaps that were suffered during and after the previous transition phases of any type of aircraft, and then to start building up from them. By this way, the authors planned to figure out the common transition concerns, design a flight scenario that would cover the most possible human errors along with a task analysis of that particular mission scenario, and then run a simulator or part-task trainer-based experiment to observe the human error tendencies of pilots from various flight backgrounds. These steps could provide to the authors enough bases to analyze the common errors and finally offer training guides considering the different aircraft types before JSF.

Throughout the thesis research, the authors realized that there is no specific transition study available in public sources that would be directly useful for the thesis, but only negative transfer of training studies, which is a dominating factor in transition accidents. While brainstorming about how to put these ideas together most efficiently, the authors had a chance to make a field trip to Lockheed Martin in Fort Worth, Texas. The preliminary survey held during this trip of the pilots experiencing the JSF mission simulator has totally changed the insight about this study, which will be explained in detail later on.

The authors think that explaining the reasons and background of this change itself will provide a broad perspective about the major Human Factors considerations and shifts of the required skills in JSF.

This chapter mentions the initial thesis plan; discusses the field trip to the Lockheed Martin facilities in Fort Worth for preliminary surveys, interviews, and personal experience in an unclassified simulator; and explains the modified plan with the rationale behind it.

## **1. Initial Plan**

The initial plan of this thesis was to seek NTT issues that may be encountered during the transition period. The main human factors concern was considered to be problems during transition period, and no other areas were thought to pose problems afterward. But the trip to Lockheed Martin changed the strategy, and the authors felt impelled revise the thesis strategy. This chapter explains the process of this revision throughout this research.

### ***a. Negative Transfer of Training***

Accidents expedite investigation and research on causes and solutions. Accidents also motivate pilots in training to understand the circumstances and to avoid them in the future.

Repetition is one of the key components of learning. If a particular procedure or action is followed regularly for a period, it turns into an automated response and the human brain takes care of that procedure without the need to pay attention to that process. This phenomenon can be explained by the following example. In the first few weeks of driving of a car, one needs to check the locations of the controls of some systems, such as air conditioning, turn signals, windows, etc. After some time, the operator gets used to their locations and can control them even without double-checking. This is because our brain matches that location with that particular system, and one does not need to direct his attention especially to these small operational issues. He just sends signals to his brain that he wants to switch the lanes and take the left one, his body takes the necessary action automatically and operates the signal handle even without thinking. Now imagine that he changes his car, and it has a different user interface in which the signal handle works the opposite way. In the beginning,

when he wants to switch lanes, he will find himself giving the signal to wrong direction, thus causing some confusion for him, and probably unsafe situations for the traffic flow. This “negative transfer of training (NTT)” is a common phenomenon. Boldovici (1987) explains it as “Practicing Task A interferes with learning or performing Task B” (p. 239). When imagining this scenario on the ground, it does not sound that critical. However, when things require a quicker response, this kind of confusion might pose a life threatening safety problem. This is why pilots are prone to safety problems in transition to a new type of aircraft more than at any other time. Experiences and automated reflexes are hard to unlearn and replace with new ones. Aviation is a very demanding task both physically and mentally. Therefore, pilots are required to follow certain procedures, usually in very short time periods. This poses a very insidious danger for pilots, especially for those who have gained strong habits after many flight hours in another type. As pilots acquired many automated skills, this becomes a concern especially during transition phases. Apparently, it is hard to learn the new operational procedures that conflict with experience.

This phenomenon formed the basis of the initial thesis plan: to identify and point out the possible areas prone to NTT. The major expectation was to identify switches operating in an adverse way or critical switches in a different location, and those operational or display concepts conflicting with experiences depending on particular flight experience. For instance, the so-called “Jettison” switch in JSF could be in the same location as the “Master Arm” switch of a previous type. This could lead to problems such as an inadvertent jettison of the stores while trying to arm them. Another instance could be symbology conventions that operate in a different way to indicate the state of the aircraft or some avionic systems.

#### ***b. Task Analysis***

Besides identifying the switches or displays that might cause problems, the authors also considered the operational procedures required in

typical mission scenarios. Air Force officials provided some secret documents about JSF that included how to operate the avionics and other Pilot Vehicle Interfaces. Those documents are meant to be used for a task analysis in order to capture the differences between the JSF and current types. The next step of the task analysis plan was to identify the potentially problematic mission types that may pose greater risk to pilots, and then conduct the analysis on those missions. The opinions from the field trip and the information provided by the documents changed this plan. The major reason preventing the task analysis was the documents; they were more like technical manuals than operating procedures with checklist items. Thus, they could not provide enough background to support a robust task analysis.

### ***c. Experiment***

An experiment was an important part of the initial plan to support the thesis with statistical results. The authors planned to focus on some research questions after evaluating the preliminary survey results, and analyzing pilot interface differences of JSF and previous types. The next step was to devise an experiment scenario, probably similar to the one used in task analysis, which could enable the authors to cover most of the possible issues. The steps above would give the basis for experimental questions and once the access to either PC trainer or unclassified simulator was given, experiments could be conducted for those questions.

### ***d. Security Classification and Required Literature***

The JSF project is currently engaging in flight and systems tests, and even though there is no major change presumed, there are still some developments especially in the Pilot Vehicle Interface (PVI) of the aircraft. This fact brings commercial security issues along with military security ones. All the documents about JSF require a very high level of security clearance. As the authors of this study, our advisors and we had this clearance; however, this is a major issue for the post-thesis as well as experimentation period. Considering

the entities that could make use of or evaluate this study, security would be a major problem and most of them would not even be able to read it. So, at some point a compromise had to be made in either the scope of study, or the benefits that could be gained from it. Another issue would be giving the participants' access to the classified documents or devices during the experiment.

**e. *The Problems Experienced***

The first problem, as mentioned before, was the scarcity of the literature on studying the transition periods. The reason could be the security issues of the military. In addition to the lack of a similar transition study, there were also relatively few studies on negative transfer of training in aviation in general. Available resources also included U.S. military reports, yet there were problems in finding appropriate studies for this thesis.

The second and most significant problem was the security issue. Even if the authors could experience the unclassified Pilot Vehicle Interface (PVI) unit, the security measures prevented them from using any training or demonstration device of JSF for any further research and experiment efforts on this equipment. Therefore, an experiment devised by the authors would not be highly related to the PVI of JSF.

In order to conduct a task analysis robustly, one has to have enough resources relevant to the operational procedures and enough insight to the context. In this case, the authors have flight experience with the F-16 and its operational procedures. Even if they did not have any flight experience with JSF, access to the operational procedures of the chosen mission scenarios could provide acceptable task analysis on JSF.

Typical checklists provide sequential procedures about how to operate systems on board, as well as emergency procedures (e.g., "Battery – ON, Check – Battery ON light"), and these procedures are to be followed during the related tasks. However, this information alone is not enough for a task analysis, because checklist information covers how to operate systems and the

actions to be taken in case of problems. It does not cover the interaction between the pilot and switches or displays. The document known as “-1” (Operating Manual) among aviators is needed for this purpose. The documents provided in this case were more technical documents than an operational manual. They had technical information that would be useful to explain how to operate individual systems; however, there was hardly any information to enable one to understand JSF sequential operational procedures. Conducting a task analysis with these resources could lead to wrong conclusions. For these reasons, the initial thesis plan was revised, which will be discussed in the following chapters.

## **2. Preliminary Survey**

Ten fighter pilots were assigned to fly the JSF simulator. Pilots had flight experience at different levels, both on flight hours and aircraft types. They were assigned to fly various missions, both Air-to-Air and Air-to-Ground, and they employed various weapons accordingly. They flew the simulator missions from the beginning of tactical scenarios, and stopped by the end of each scenario. They skipped ground procedures, take-off and landing phases, and the navigation phases. Even if these are major phases to be analyzed for a transition study, the authors think that the available mission phases were still sufficient to support the objective of this thesis. This gave a perfect opportunity to determine the PVI issues of the JSF cockpit, at first hand.

The opinions of the pilots were highly valuable for two reasons. First, these pilots have the same kind of flight training and experience as those who will fly JSF in the very near future, and some of them probably will do so. So, what they experienced in the simulator will not be much different than what will be experienced in the future, and most probably there will be even more issues due to additional tasks. Second, this was the first JSF simulator experience for most of the ten pilots. Therefore, this was a relatively similar first exposure scenario even if they did not receive all ground training that the actual JSF pilots

will. The lack of ground training could be beneficial for the study, because the possible NTT issues would be more apparent. Another point was that the participants came to the study from flying experience with varying fighter platforms, so the need was anticipated to figure out the differences and similarities between pilots of various types, and also their transition suitability to this new platform.

To validate whether the study's initial plan was on the right track, the authors prepared a preliminary survey with open-ended questions. The main objective was to have a general understanding of problematic areas and to validate the approach of this study. The questions were related to general human factors issues and did not require any answers with security classification.

The preliminary survey questions were as follows:

1. What is your first impression about JSF?
2. What are the specific strengths and weaknesses of JSF? (Pilot cockpit interaction)
3. What are the similarities/differences of JSF from your current type of aircraft?
4. Where do you think the potential areas are that might be difficult for a transition pilot from your current type of aircraft?
5. Generally, is the data represented to the pilot at a sufficient level, or did it happen that you became overwhelmed by over-representation/finding and filtering necessary information?
6. Considering your current aircraft type, is there any system in JSF that serves the same purpose with different operation principles/data representation/interface/interaction?
7. Comparing the JSF cockpit with your current type, is there any interface/switch that looks similar, and/or is in the same location, but used for another system/purpose?
8. What are your impressions about the specifications of HMD? (Weight, dimensions, Field of View, contrast and brightness range and settings)

9. Does the HMD take your focus/attention from priority issues and distract you from prioritized task?
10. Do you have any previous HUD/HMD experience? If so, are there any differences? (data representation locations, style and colors)
11. What are your impressions about the usage and switching of HMD modes and its data representation?
12. What is your general impression about HMD? What are its specific strengths and weaknesses?
13. Do you have any previous MFD experience? If so, are there any differences? (data representation locations, style and colors)
14. What are your impressions about the usage and switching of MFD modes and its data representation?
15. Does the increased symbology confuse/overwhelm you?
16. What is your general impression about MFD? What are its specific strengths and weaknesses?
17. What is your impression about seat/stick/throttle positioning and their usage?
18. What is your impression about switch positioning on throttle/stick? Is there any switch that results in confusion or contradicts your previous experience?
19. What is your impression about 3D audio in operational usage?
20. Are there any issues regarding the order sequence of operational procedures between the JSF and your current type?
21. In which type of missions/flight phases, is the workload of the pilot increased?
22. What are the effects of increased automation on your workload, SA and flight concentration?
23. What would you like it to be changed in cockpit, and how?
24. What do you think a pilot in your position would have to learn and/or unlearn to fly JSF?

As they are straightforward, the questions only require general human factors and PVI issues, but not any specific information about any systems. The main intent is to capture the potential threats or problematic areas for various aircraft types along with any NTT issues. The preliminary survey was handed to the participants after they had approximately six missions in the simulator, and still had at least this much more to fly, so that they could focus on human factors issues with the consideration of survey questions.

### **3. Interviews**

It is always a possibility that researchers might miss some important points in their survey questions. That was the main reason it was decided to interview the participants in addition to the preliminary survey. The advantage was that the authors also are fighter pilots and have the same language and background with participants. This helped a lot while capturing unmentioned points in the survey, and enabled coverage of broader areas.

Considering the flexibility of a mutual conversation, and the opportunity to interview all the participants, the authors went over the questions one by one. Noting the process, they could go deeper into the issues that each participant brought to the table. The authors mentioned their own experience with the unclassified PVI device to the participants, and discussed their experience on the same issues. Since everyone had a different approach to answering the survey questions, the authors also crosschecked the answers given by other participants to validate answers as much as possible. In conclusion, the interviews supported the findings from the survey, enabled the authors to go deeper on many subjects, and provided more valid results.

### **4. The Unclassified Simulator**

The unclassified simulator had the full cockpit interfaces. It was restricted on any weapon employment procedures, but capable of all other flight tasks. The authors flew the simulator approximately 30 minutes each, and performed take-off, basic navigation, acrobatic maneuvers, operation of the portals (4 MFD

Windows) on the primary LCD display, and landing. They did not have an opportunity to experience the revolutionary Helmet Mounted Display (HMD) and related systems that work accordingly with it such as Distributed Aperture System.

## **B. FOLLOW-ON SURVEY**

### **1. General Information**

The trip to Lockheed Martin in Fort Worth, TX changed the track of this thesis substantially. Both the initial and revised thesis plans are thoroughly discussed in the related chapter, but the major point is that there was a need to identify the human factors concerns further and in more detail before proceeding with the scientific process of proposing solutions and testing them. This need was the basis for the follow-on survey that will be discussed in this chapter. As the initial survey consisted of open-ended questions, and the interviews yielded important but general results, the authors decided to construct a survey based on their experience from the trip and the literature in a more quantifiable way. The following sections will explain the follow-on survey in more detail.

#### ***a. The Structure of the Follow-on Survey***

The objectives of the following survey were different than the initial survey. The main objective of the follow-on survey was to identify the possible human factors concerns in JSF. The reason to conduct a second survey was twofold. First, the initial trip with the survey, interviews and self-experience in unclassified simulator yielded different results than the authors predicted the human factors issues in JSF would be. And secondly, whatever results the initial survey yielded, they were in an open-ended format. Many issues emerged from the interviews and initial survey in totally unquantifiable ways. Thus, the objectives of the follow-on survey were to confirm the areas that emerged strongly in the initial survey, to further investigate the areas that emerged weakly, to get the opinions of the participants to solve the possible problems and still provide participants some open-ended questions related to both problem

identification and solutions. One of the important points is the structure itself. The initial survey consisted of totally open-ended answers, whereas the follow-on survey benefited from a Likert scale in seven levels. This process helped the authors to understand the agreement levels of the participants more accurately than the initial survey.

Another important factor for the follow-on survey was to capture all of the areas, systems, or parts of the missions from a human factors perspective. For this reason, the survey is divided into five segments.

In the first segment, the questions try to capture and confirm the important points about controlling the aircraft and the possible use of autopilot in JSF. Whether or not the basic manual flight skills will be also important in JSF, the usability, operation and expected usage of the autopilot are the areas the questions investigate.

Two of the apparent changes or differences of JSF from previous generations are its modern and capable systems, and the unique display suite for pilot vehicle interfaces. And those areas are questioned in the second segment of the survey. Whether it is hard to learn how to operate the systems and menus, the systems needing higher workloads that are prone to cause disorientation and SA related problems, and which are prone to fixation were among the areas investigated in this segment of the survey.

The third segment is inspired by the prediction that the JSF will mainly require mental skills and cognitive resources due to high information load provided to pilots and its improved overall capabilities provided by new and improved systems. The possibility of informational overload, data filtering issues, task overload and workload concerns, demand for mental resources and abilities and other attentional areas are investigated in this segment.

It is commonly accepted that the flight mission begins with the preparations before flight, and ends with the debriefing. The more capable an airplane is, the more preparation time, briefing and debriefing time it needs.

Because there are more capabilities and more sophisticated systems, there must be better preparation, more detailed briefings and further coordination among the formation members. In order to predict the concerns about the mission planning and briefings, the fourth segment of the survey contains questions about the possible use of simulators and desktop trainers.

It is inevitable to miss some of the factors during the surveys, and that is the reason for including a segment with open-ended questions. The fifth segment of the follow-on survey attempts to learn pilots' opinions about many important issues of JSF from a human factors perspective. The most important safety and training concerns the participants foresight, the prediction for the transition phase, whether tactical experience of the pilots was important for the transition phase, and becoming combat-ready faster in JSF; these are among the areas the segment investigated. Likert Style Survey items were used, in which participants indicated agreement with these statements from disagree to agree.

Follow-on survey questions were constructed as follows:

*Question 1:* There will be much more use of "autopilot" in the JSF compared to my current aircraft type.

*Question 2:* No matter how good the autopilot is, pilots will still need to train basic flying skills as much as previous type.

*Question 3:* Use of the JSF autopilot will greatly help pilots to focus on the tactical situation.

*Question 4:* The autopilot and other cockpit automation will result in possible loss of situational awareness regarding the state of the aircraft position control and flight status.

*Question 5:* The various flight operating modes in the JSF are easy to learn and distinguish.

*Question 6:* It is easy to switch between the modes of autopilot and transit from autopilot to manual flying.

*Question 7:* The pilot can easily capture any problems of autopilot (awareness of aviate & navigate the A/C) when accomplishing other tactical tasks in the cockpit.

*Question 8:* Because the autopilot of JSF is highly sophisticated and has various modes, basic flying skills are not required as much as it is required at previous types of aircrafts.

*Question 9:* Based on my experience in the JSF simulator, I believe that the flight management system is easy to set up and operate.

*Question 10:* There are some modes in the flight management system that I found difficult to use.

*Question 11:* There were instances that I encountered when flying the JSF simulator for which I did not understand how to activate or use the appropriate operating mode.

*Question 12:* As far as I can tell there should be no difficulty learning how to configure the cockpit displays for flying, navigating and communicating.

*Question 13:* It may take extra training time for pilots to learn how to effectively operate the new JSF cockpit controls and displays.

*Question 14:* There had been instances that I had to focus my attention mostly to head-down displays to manage the systems and reach the information I needed.

*Question 15:* Even if there is a lot of information from various sensors on the same display, I did not have any difficulty to filter and evaluate the data for decision-making.

*Question 16:* DAS can cause disorientation under some conditions.

*Question 17:* The idea of seeing HMD symbology wherever I look did not distract my attention.

*Question 18:* I believe the HMD failure will dramatically affect the mission efficiency.

*Question 19:* Managing the switches on throttle and stick effectively will require a considerable amount of experience and training.

*Question 20:* The appeal of the head-down displays and the workload need to be done on those displays might cause flight safety issues.

*Question 21:* I believe that there needs to be special training to teach pilots how to use the expanded display suite.

*Question 22:* Without proper training and experience pilots may not be able to handle the vast amount of information provided by the JSF system.

*Question 23:* I believe the main task of the pilot will switch from mostly flying the aircraft to making tactical decisions.

*Question 24:* Being able to follow the whole tactical arena did not affect my focus on my own target/area of interest.

*Question 25:* Managing both A/A and A/G data at the same time will overload pilots under some tactical situations.

*Question 26:* I felt the need to effectively filter and declutter the presented information in most tactical situations.

*Question 27:* Even if JSF presents a very good tactical picture, a high level of tactical experience is required to be able to use the capabilities of the aircraft to the utmost extent.

*Question 28:* Compared to my current type of aircraft, the training period should be longer to comprehend the systems thoroughly and fly the aircraft at its capabilities.

*Question 29:* The new concept of JSF requires building and maintaining better SA and more cognitive workload than my current type of aircraft.

*Question 30:* There were some instances where I had difficulties at shifting my attention between the overall tactical picture and my task related tactical picture.

*Question 31:* I believe a longer pre-flight preparation is needed for JSF.

*Question 32:* Even if the systems enhance in-flight mutual support at a great level, formation briefing and coordination are even more critical than for previous types.

*Question 33:* The simulator flights and real flights should be exactly similar in terms of briefing, mission and debriefing.

*Question 34:* PC trainers donated with real throttle and stick controls would be significantly beneficial to improve the systems management skills of pilots.

*Question 35:* To improve the pilots' display suite management and tactical picture assessment skills, alternative-training systems on the ground will be helpful other than actual flight conditions.

Open-ended questions are constructed as follows:

*Question 1:* What do you foresee as the most significant problems or training issues? Briefly describe.

*Question 2:* Which one of the following pilot types do you think will qualify to effectively and safely fly all the missions with JSF earlier in transition phase: a pilot who gained experience in another aircraft type, or a new graduate pilot from flight school? Why?

*Question 3:* What might be the most likely cause for flight safety problems in JSF?

*Question 4:* What would be your recommendations about the transition and training phase of JSF?

*Question 5:* Other Comments

### ***b. Participants***

The participants of the initial and follow-on surveys, as well as the interviews have strengths in terms of scientific approach, but some other points are the drawbacks that limit the power of the results.

There were same 10 participants for both the initial and follow-on surveys (N=10). Eight of them are current F-16 pilots, and two of them are current F-4 pilots. All of them have both Air-to-Air and Air-to-Ground experience, and the major positive side for the participants is that they were representative for the sake of the study. All of them have the common flight backgrounds and training that the JSF pilots will have in the Turkish Air Force. They are all fighter pilots from various aircraft types flown in TuAF and are qualified to perform as mission commanders.

If the sample size included many more participants from various types of fighter aircraft, it would be possible to compare the results depending on the aircraft origins. This could give important clues for each aircraft type. It is possible that pilots of one aircraft type could think an issue as a possible problem, whereas other type's pilots wouldn't.

The last limiting factor is that the pilots were all from the same country. The JSF will be flown in many countries, and because the pilots' training and abilities may vary depending on the countries, participants from other countries could provide a broader spectrum for human factors under investigation.

The reason for not having a larger sample size was the security and accessibility issues of the JSF project. JSF is under development and has commercial security issues as well as military security concerns.

It is also necessary to mention the experiences of the participants with JSF. Obviously, the actual pilots transitioning to JSF will undergo very demanding ground training phases before they step into the actual aircraft, but this was not the case with participants. They were provided with PVI documents

required to operate the necessary systems in the cockpit and had a couple of weeks to study them. It is legitimate to say that the participants are not at the same experience and knowledge level that the actual transition pilots will be, but in contrast they were also not experiencing the actual, real missions. It is to be expected that the real missions will pose higher levels of risk/stressors, and will be much more demanding than the simulator missions they flew.

The second important issue about the participants on JSF experience is the missions they flew in the simulators. They flew the classified mission simulator for both Air-to-Air and Air-to-Ground missions for two weeks. The positive side of their experience can be seen in that it was their first exposure to the JSF, as it will be for the first transition pilots in the future; thus, their opinions are important for providing first glance input. In the second week, they also had little more experience than a first glance exposure, and provided helpful feedback. But again there is the important factor of actual versus simulator missions. The actual aircraft will have full cockpit capabilities once released to the air forces, and the missions will be higher risk, and much more stressful and demanding.

Even though there were several shortcomings due to the restricted sample, the authors believe that the results are reliable enough for initial problem identification and human factors concerns investigation.

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## **IV. RESULTS AND DISCUSSION**

### **A. PRELIMINARY SURVEY WITH INTERVIEW RESULTS**

#### **1. Findings from Interviews, Preliminary Survey and Own Simulator Experience**

Overall, the iterative answers to both the preliminary survey and the interview topics revealed the following outcomes for each question.

Briefly, the survey and interview results indicated that the most significant issue will not be the negative transfer of training, contrary to what was expected. The major issues about the transition to JSF appear to be adaptation to new technologies on combined flight displays; ability to evaluate, comprehend and use the vast amount of information collected from various sensors covering all the aircraft; and operating the automated systems. The findings showed that the challenge for the pilots is going to be the increased mental workload compared to previous aircraft.

#### ***a. Summary of Preliminary Survey Findings***

The following answers were selected from the preliminary survey and interviews and are the most agreed upon ones about particular questions, or sometimes the interesting ones. For convenience, the authors did not write down the entire answers one by one, but rather summarized them by common explanations as much as possible.

##### **1. What is your first impression about JSF?**

Almost all of the participants expressed their first impression that they were not expecting such a modern and capable fighter. The most significant important input about this question was that the JSF cockpit and PVI were highly adaptable. The authors were expecting to get some answers that could be attributed to negative transfer of training, yet there was no answer to indicate that. One of the strongest comments about the JSF cockpit interface was that it

will require a lot more mental workload and situational awareness to be able to use all the information presented to the pilots. There were many occasions where the participants commented that there might be SA related accidents, mishaps and losses due to overwhelming task load and frustration.

2. What are the specific strengths and weaknesses of JSF (Pilot cockpit interaction)?

The common opinion about this question was that the capabilities of the aircraft were both its strengths and its weaknesses. They were the strengths as they improve the mission effectiveness dramatically, yet weaknesses in that they require considerable amounts of mental effort to operate compared to previous types. Obtaining information is not a challenge as before, but filtering, evaluating and making decisions while flying the jet were seen as a potential hazard for an inexperienced pilot. Most of the participants believe that the use of the autopilot will be required in some conditions due to excessive mental workload.

3. What are the similarities/differences of JSF from your current type of aircraft?

The most obvious agreement among the pilots about the difference of JSF from their current types was that JSF required more mental effort. The pilots having relatively less modern cockpits found the logic in operating the modern systems easy, and others who already operate a glass cockpit similar to JSF found the operational procedures to be similar or if different, easy to adapt.

4. Where do you think the potential areas are that might be difficult for a transition pilot from your current type of aircraft?

The participants considered managing all information provided in the cockpit to be a major challenge. They thought that this issue needs to be addressed carefully during the initial phases of training via all training devices including the simulator.

5. Generally, is the data represented to the pilot at sufficient level, or did it happen that you became overwhelmed by over-representation/finding and filtering necessary information?

There is more information being presented to pilots than ever before, but the problem is to manage that much information.

6. Considering your current aircraft type, is there any system in JSF that serves the same purpose with different operation principles/data representation/interface/interaction?

No significant issue reported about this question.

7. Comparing the JSF cockpit with your current type, is there any interface/switch that looks similar, and/or is in the same location, but used for another system/purpose?

No significant issue reported about this question.

8. What are your impressions about the specifications of HMD (Weight, dimensions, Field of View, contrast and brightness range and settings)?

It is accepted as a very useful system helping pilots to build up their SA. The more experienced pilots consider the HMD and DAS combined usage as a potential threat due to some conditions that might lead to disorientation, and thus result in an undesirable event.

9. Does the HMD take your focus/attention from priority issues and distract you from prioritized tasks?

In general, the HMD symbology did not prevent participants from focusing on events outside the cockpit, but while “seeing through” the fuselage and through the other cockpit displays, some participants found it disorienting initially, and commented about being extra cautious to use this system especially at low altitude flights and in bad weather conditions.

10. What are your impressions about the usage and switching of HMD modes and its data representation?

No significant issue reported about this question.

11. What are your impressions about the usage and switching of HMD modes and its data representation?

No significant issue reported about this question. Only some pilots not familiar to HMD reported that they prefer to use Head Down instruments to reach information due to their habits. However, they also stated that it is a time based issue and can be overcome in short time.

12. What is your general impression about HMD? What are its specific strengths and weaknesses?

The general conclusion about the HMD was its usefulness for pilots to enhance their mission effectiveness.

13. Do you have any previous MFD experience? If so, are there any differences (data representation locations, style and colors)?

The participants operating MFDs in their current types reported that the operational logic and the interface of similar systems in the JSF cockpit are totally different, thus posing no NTT issue.

14. What are your impressions about the usage and switching of MFD modes and its data representation?

The portals (Separate MFD Windows of the big display suite) are easy to adapt and use. However, it is stated that lacking a thorough training on modes and symbology will prevent pilots from obtaining the necessary information when needed.

15. Does the increased symbology confuse/overwhelm you?

The portals provide perfect SA, and were found to be very useful, but the existence of a lot of data and modes was considered as a major

challenge during operations, and also a means of distraction due to containing too much information at the same time; thus, it was seen as crucial to declutter the irrelevant information.

16. What is your general impression about MFD? What are its specific strengths and weaknesses?

General opinion was that the display suite enhances the pilot's SA and is very powerful as well as being useful.

17. What is your impression about seat/stick/throttle positioning and their usage?

The anthropometric design of the throttle, stick and seat, felt comfortable. There were pilots who used to fly with a more straight seat and stick in the middle of cockpit, as well as pilots who were familiar with the side stick and HOTAS switchology with slightly more seat angle to the back, yet none complained about the seat and throttle-stick setup.

18. What is your impression about switch positioning on throttle/stick? Is there any switch that results in confusion or contradicts your previous experience?

The participants using HOTAS in their current types report the HOTAS in JSF as easily adaptable. Even if there were switches at the same location or the same purpose but which operated differently, they found it very easy to adapt. They expressed the importance of its familiarization and training for an effective use because it controls even more systems than it ever has before.

19. What is your impression about 3D audio in operational usage?

The 3d audio system was not used.

20. Are there any issues regarding the order sequence of operational procedures between the JSF and your current type?

The participants stated that they did not have enough knowledge and information about the operational procedures of JSF to compare with their experience. The tasks they were supposed to perform while on JSF simulator flights covered limited operational knowledge about the JSF platform.

21. In which type of missions/flight phases, is the workload of the pilot increased?

The pilots reported that workload was especially high in low altitude missions, which require a lot more tasks to accomplish, yet do not allow pilots to use autopilot to concentrate on tactical tasks.

22. What are the effects of increased automation on your workload, SA and flight concentration?

Autopilot is considered to be very useful. Considering the high task load to maintain tactical awareness and effectively use the weapons, pilots stated that its use is necessary. Some participants even stated it is compulsory to use autopilot to effectively make best use of the aircraft systems.

23. What would you like to be changed in cockpit, and how?

No significant issue reported about human factors in cockpit.

24. What do you think a pilot in your position would have to learn and/or unlearn to fly the JSF?

Some answers include the need for a robust brain-muscle coordination, getting used to cockpit instruments and displays, and maybe starting all over again except general aviation knowledge and skills. These are also considered as the basic skills to fly any aircraft. However, besides the physical demands of flying an aircraft, JSF requires a highly adaptable mind for new technology, being able to filter and evaluate a large amount of information.

## **B. ANALYSIS OF THE FOLLOW-ON SURVEY RESULTS**

### **1. Multiple Choice Questions**

Results from the multiple-choice questions are shown in Figures 5 through 39. The histograms in these figures indicate the agreement level of participants with the related survey questions. The Y-axis indicates the number of participants for the given agreement levels. The sum of the numbers in some questions is not ten despite the fact that there were ten participants. This is because some participants stated that they had no opinion about those related questions; thus, they are not represented in these histograms. Considering that all the histograms are very self-explanatory, they are not named specifically.

The major point of the analysis is the nature of the data or answers. One could think to assign numbers between -3, and 3 to represent a value range from “strongly disagree” to “strongly agree,” and then calculate the average for each question. For instance, a typical report would be “The average agreement level for this question is 2.3.” But as the answers are categorical (ordinal), it would be wrong to apply any linear mathematical calculation to them. The moderate agreement level assigned the number 2 would not be two times stronger than the agreement level of “slightly agree” with the number 1. This is the reason for reporting the agreement levels in frequency histograms. The histograms provide the tendencies of the participants in each question graphically and numerically. After reporting each question’s histograms without any conclusion, the discussion section of this chapter will provide the summary and discussions of the results, and report the important findings of the follow-on survey.

*Question 1:* There will be much more use of “autopilot” in the JSF compared to my current aircraft type.

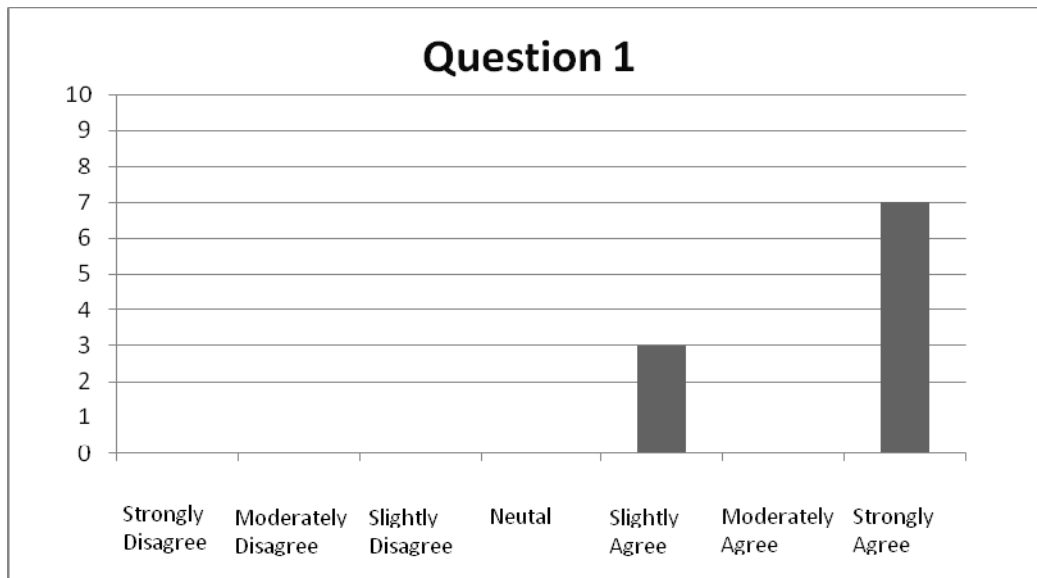


Figure 5. Answers to Question 1

*Question 2:* No matter how good the autopilot is, pilots will still need to train basic flying skills as much as previous type.

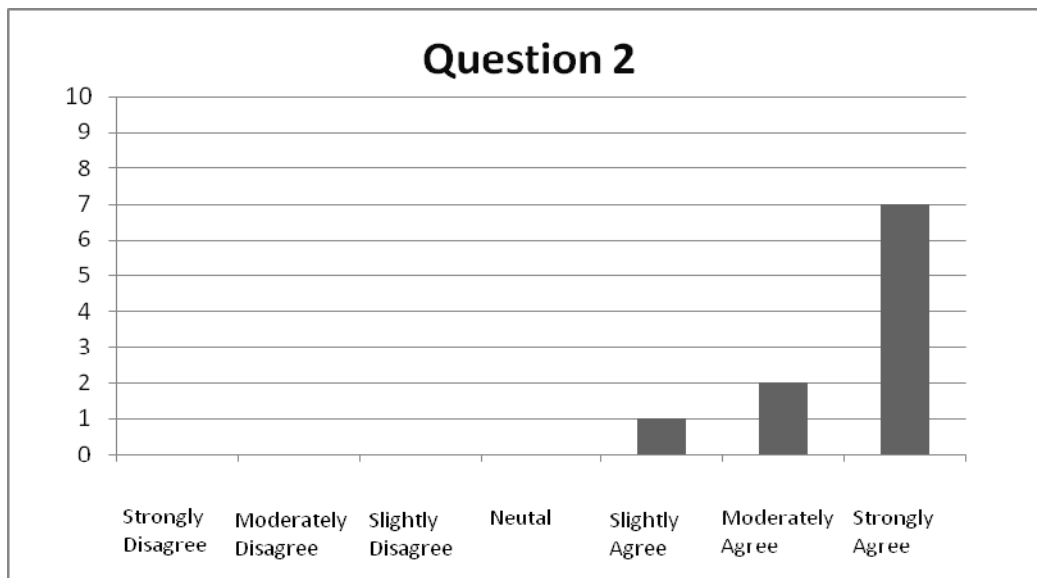


Figure 6. Answers to Question 2

*Question 3:* Use of the JSF autopilot will greatly help pilots to focus on the tactical situation.

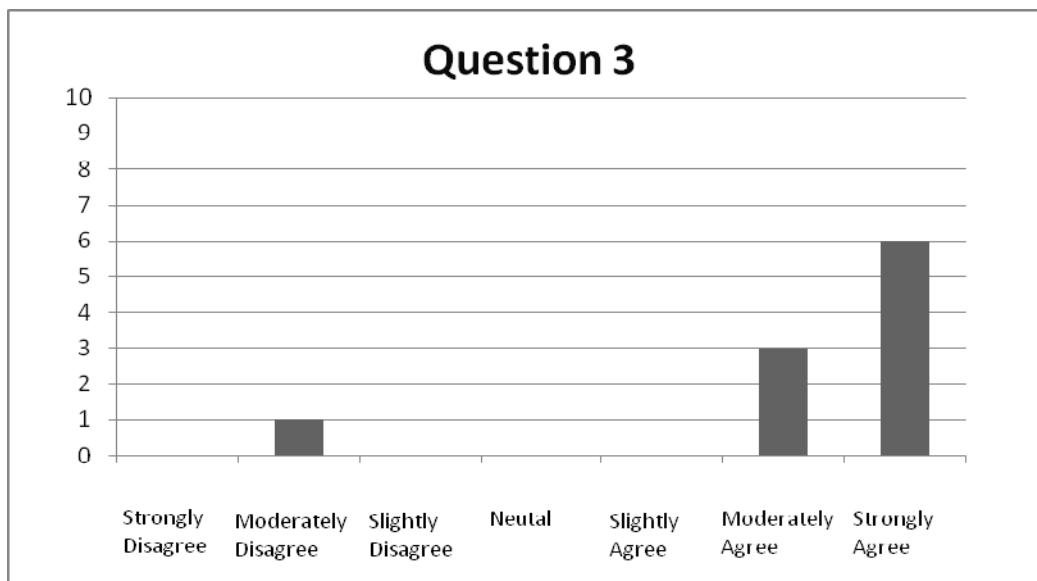


Figure 7. Answers to Question 3

*Question 4:* The autopilot and other cockpit automation will result in possible loss of situational awareness regarding the state of the aircraft position control and flight status.

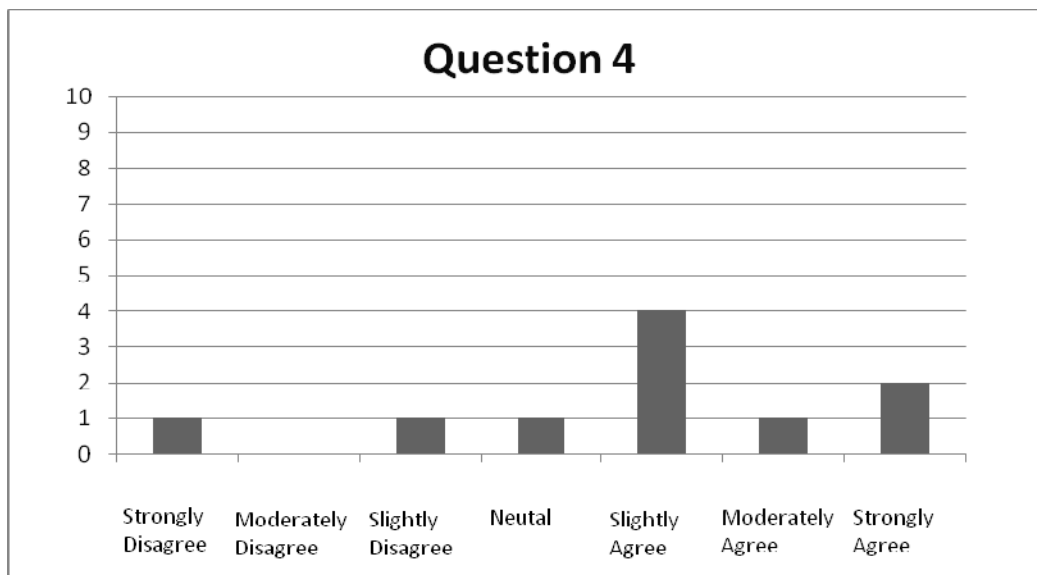


Figure 8. Answers to Question 4

*Question 5:* The various flight operating modes in the JSF are easy to learn and distinguish.

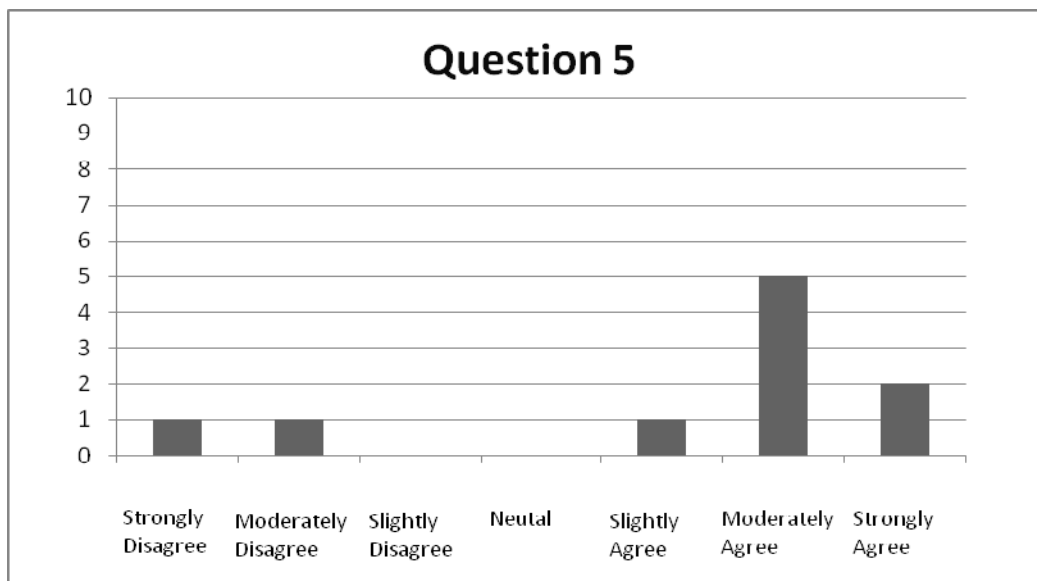


Figure 9. Answers to Question 5

*Question 6:* It is easy to switch between the modes of autopilot and transit from autopilot to manual flying.

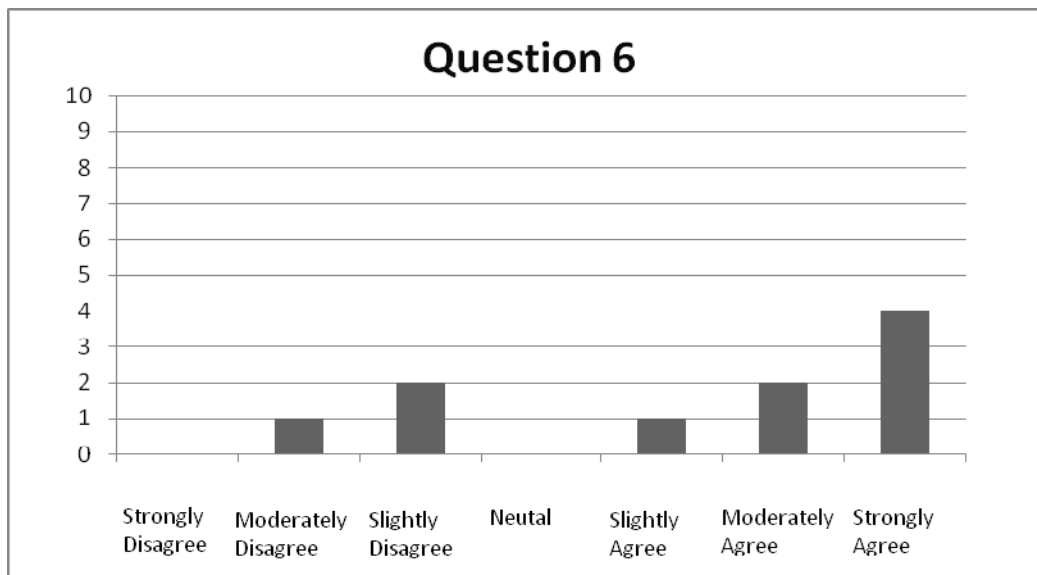


Figure 10. Answers to Question 6

*Question 7:* The pilot can easily capture any problems of autopilot (awareness of aviate & navigate the A/C) when accomplishing other tactical tasks in the cockpit.

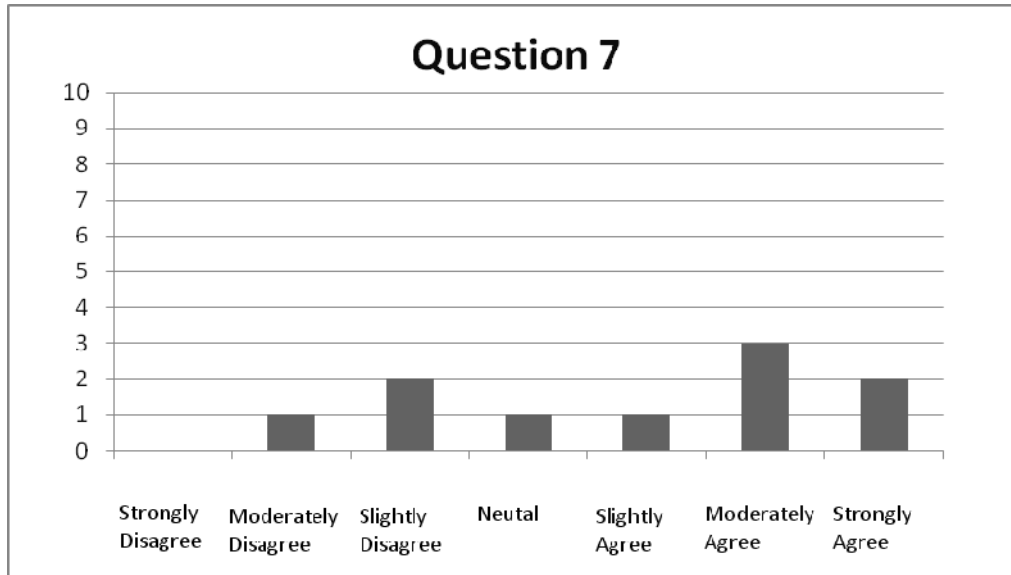


Figure 11. Answers to Question 7

*Question 8:* Because the autopilot of JSF is highly sophisticated and has various modes, basic flying skills are not required as much as it is required at previous types of aircrafts.

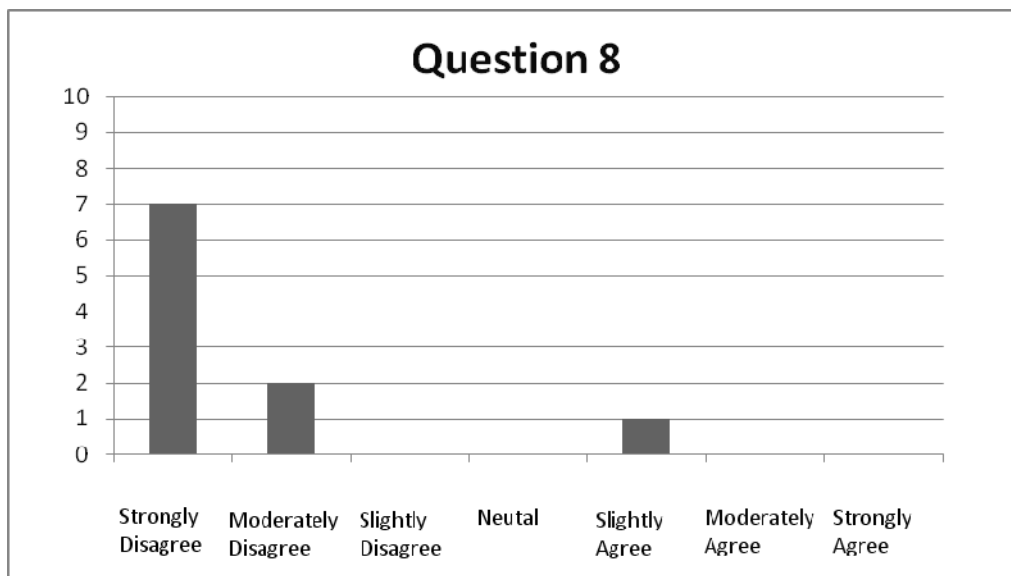


Figure 12. Answers to Question 8

*Question 9:* Based on my experience in the JSF simulator, I believe that the flight management system is easy to set up and operate.

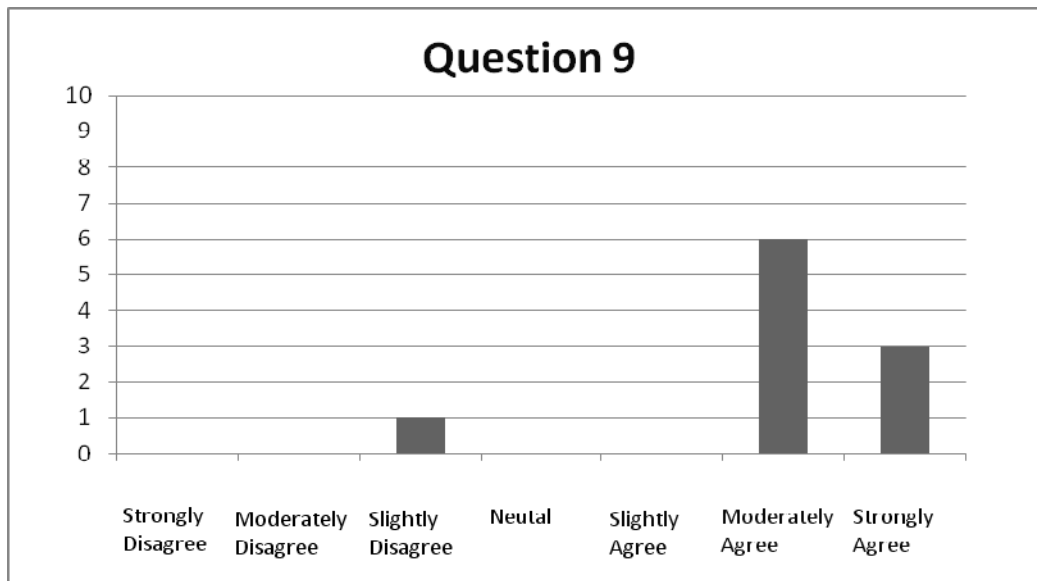


Figure 13. Answers to Question 9

*Question 10:* There are some modes in the flight management system that I found difficult to use.

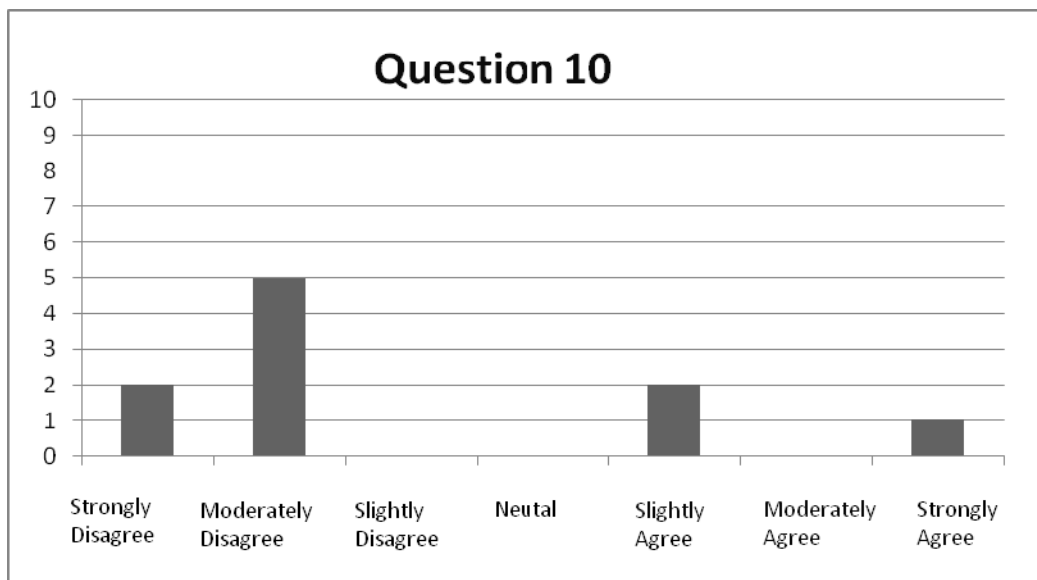


Figure 14. Answers to Question 10

*Question 11:* There were instances that I encountered when flying the JSF simulator for which I did not understand how to activate or use the appropriate operating mode.

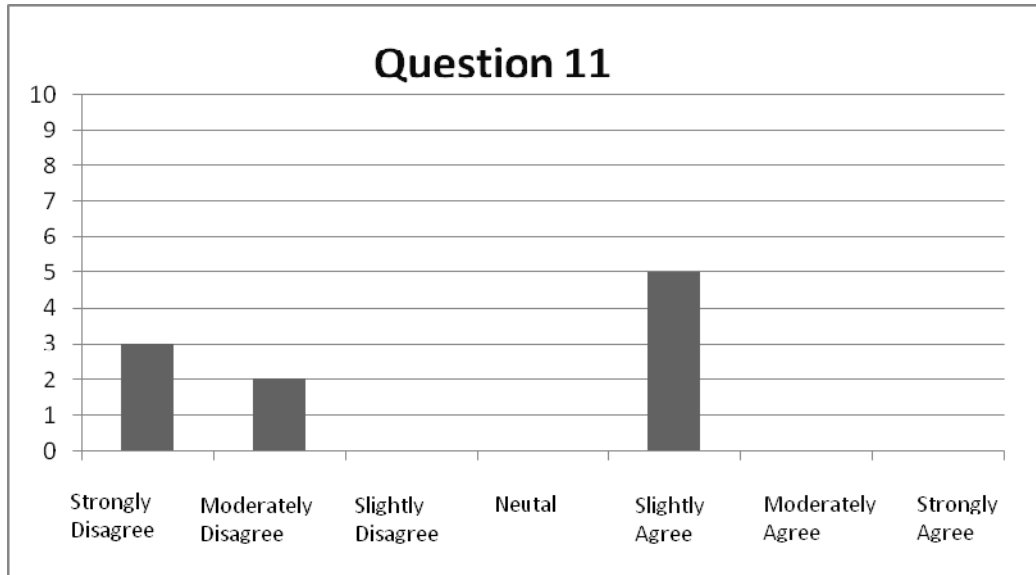


Figure 15. Answers to Question 11

*Question 12:* As far as I can tell there should be no difficulty learning how to configure the cockpit displays for flying, navigating and communicating.

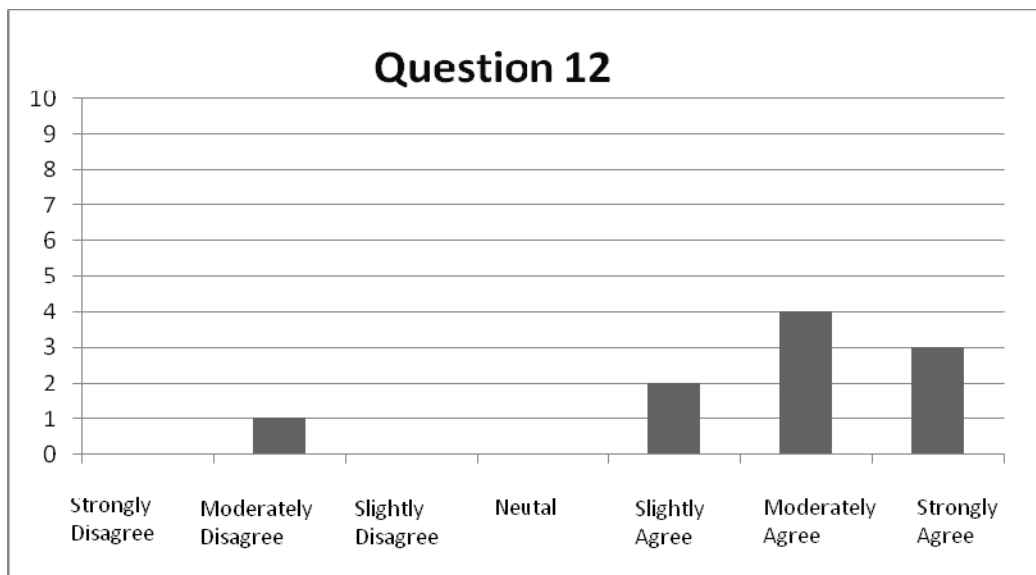


Figure 16. Answers to Question 12

*Question 13:* It may take extra training time for pilots to learn how to effectively operate the new JSF cockpit controls and displays.

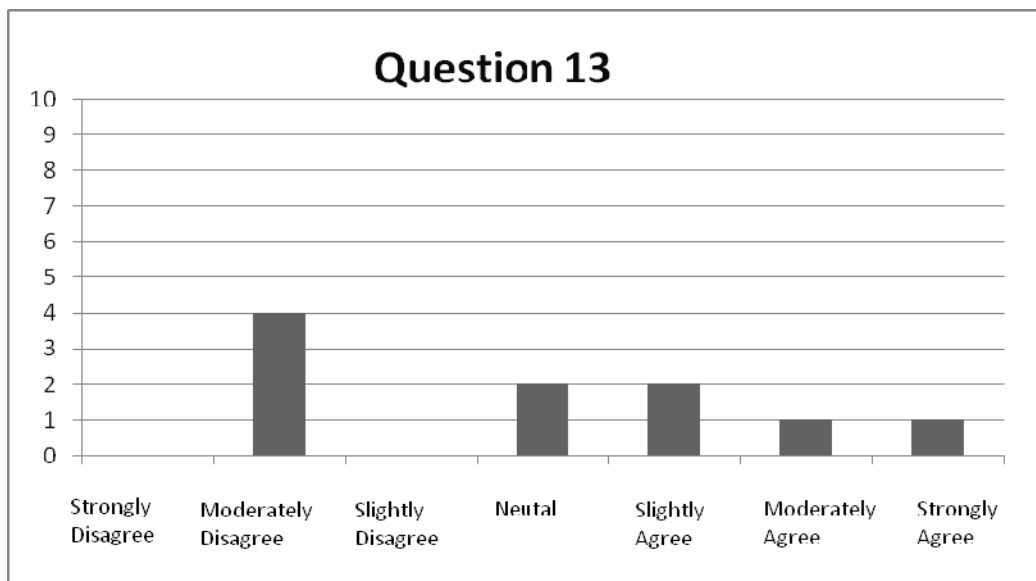


Figure 17. Answers to Question 13

*Question 14:* There had been instances that I had to focus my attention mostly to head-down displays to manage the systems and reach the information I needed.

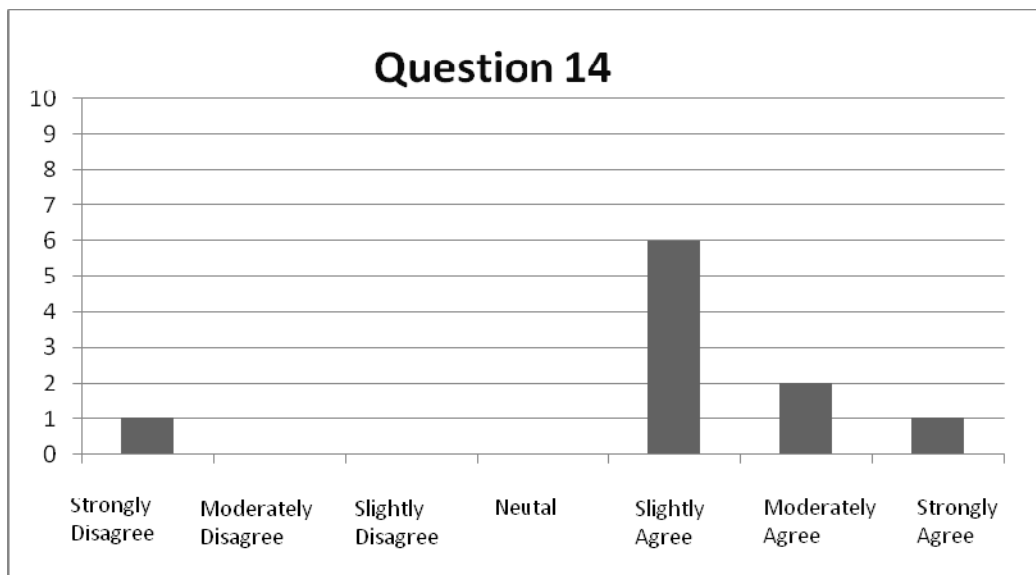


Figure 18. Answers to Question 14

*Question 15:* Even if there is a lot of information from various sensors on the same display, I did not have any difficulty to filter and evaluate the data for decision making.

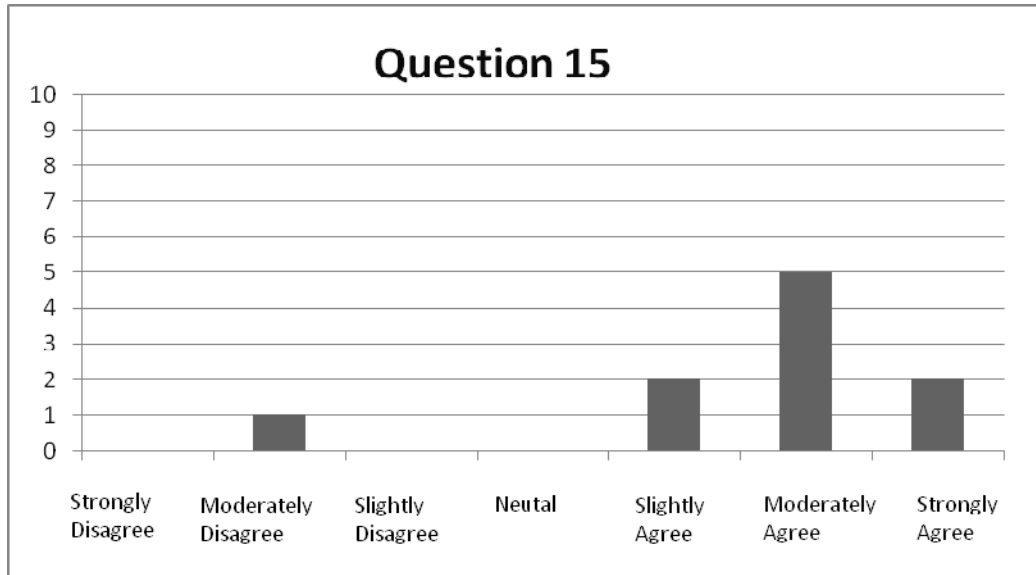


Figure 19. Answers to Question 15

*Question 16:* DAS can cause disorientation under some conditions.

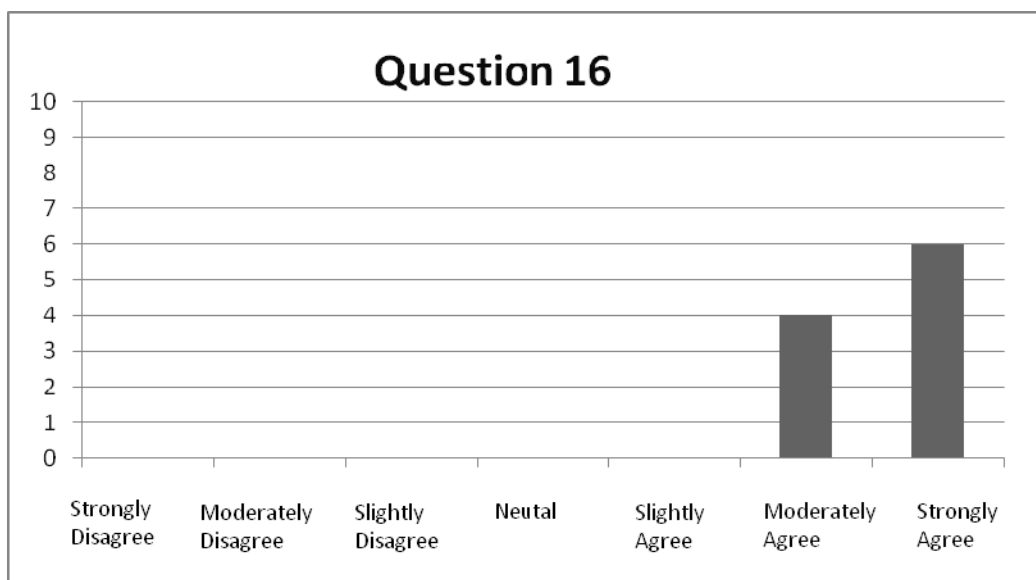


Figure 20. Answers to Question 16

*Question 17:* The idea of seeing HMD symbology wherever I look did not distract my attention.

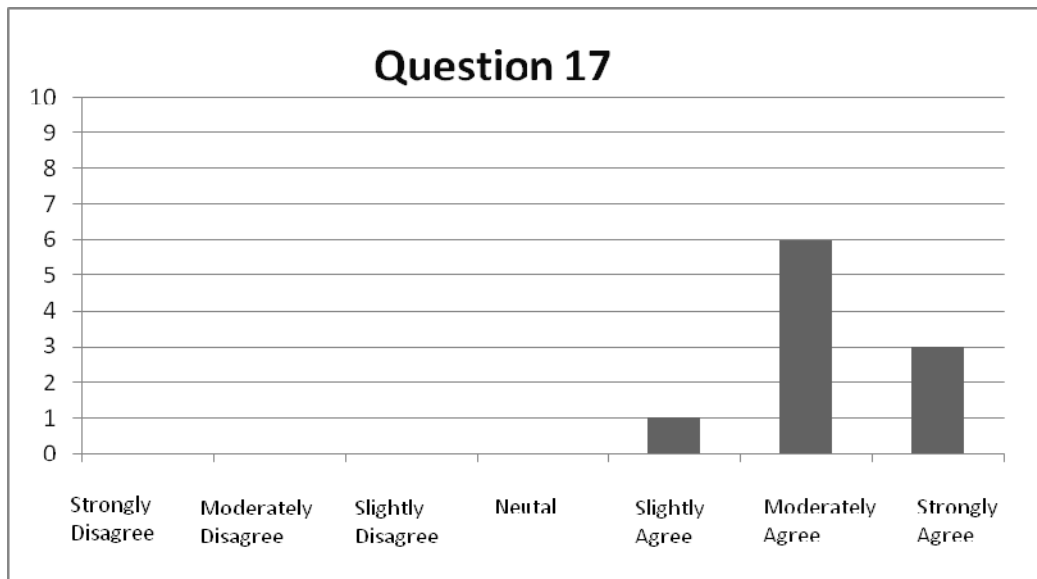


Figure 21. Answers to Question 17

*Question 18:* I believe the HMD failure will dramatically affect the mission efficiency.

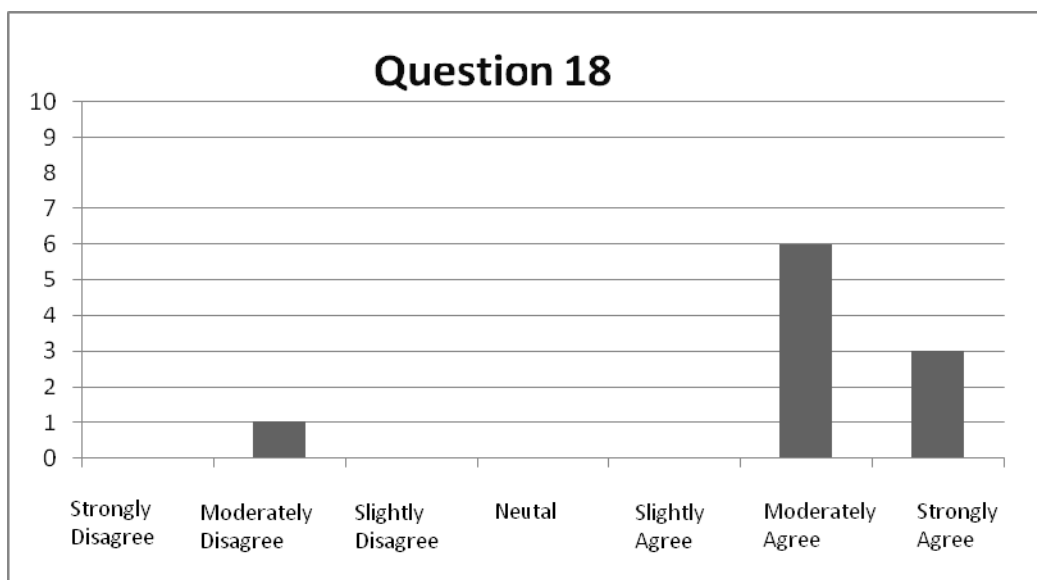


Figure 22. Answers to Question 18

*Question 19:* Managing the switches on throttle and stick effectively will require a considerable amount of experience and training.

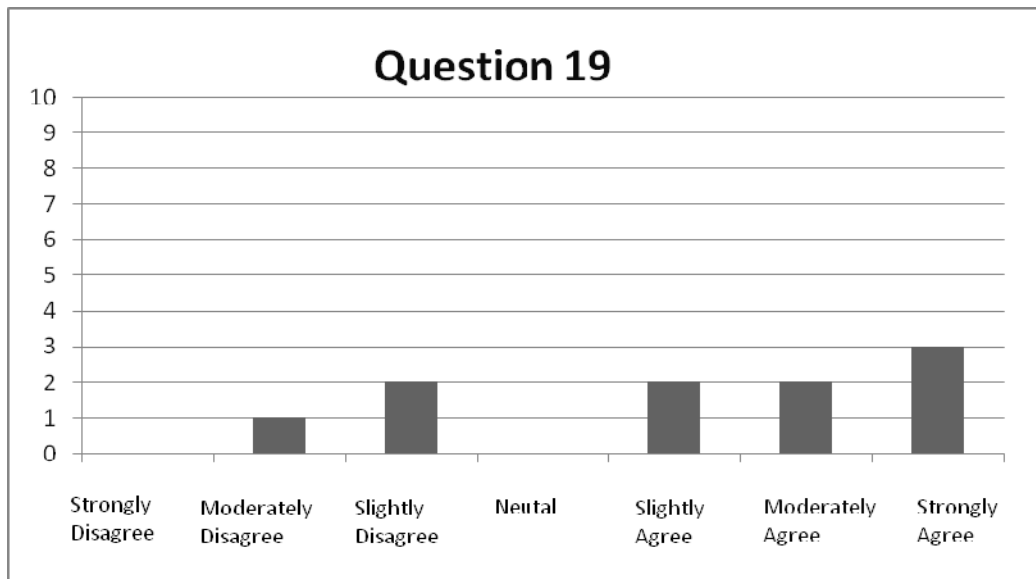


Figure 23. Answers to Question 19

*Question 20:* The appeal of the head-down displays and the workload need to be done on those displays might cause flight safety issues.

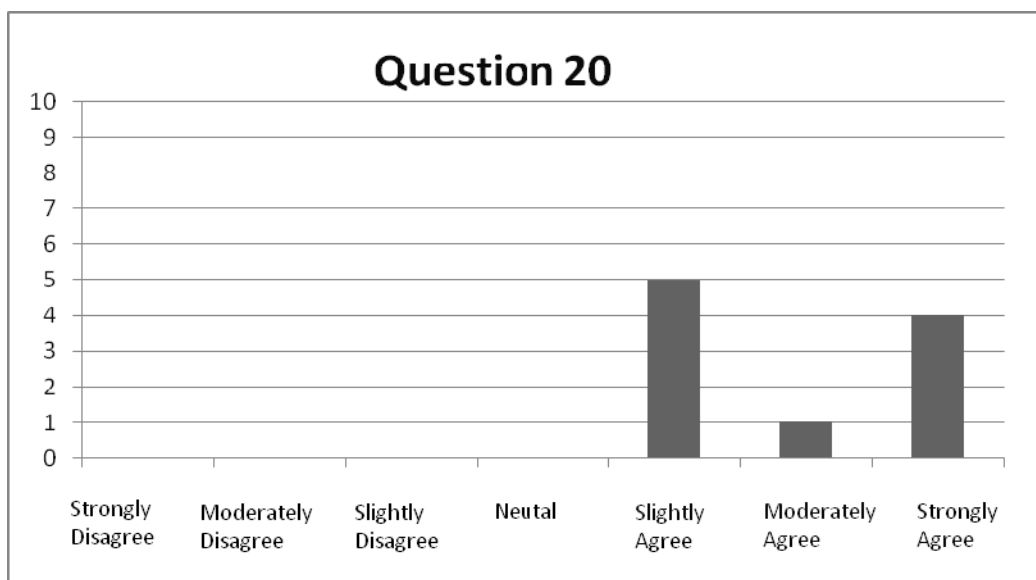


Figure 24. Answers to Question 20

*Question 21:* I believe that there needs to be special training to teach pilots how to use the expanded display suite.

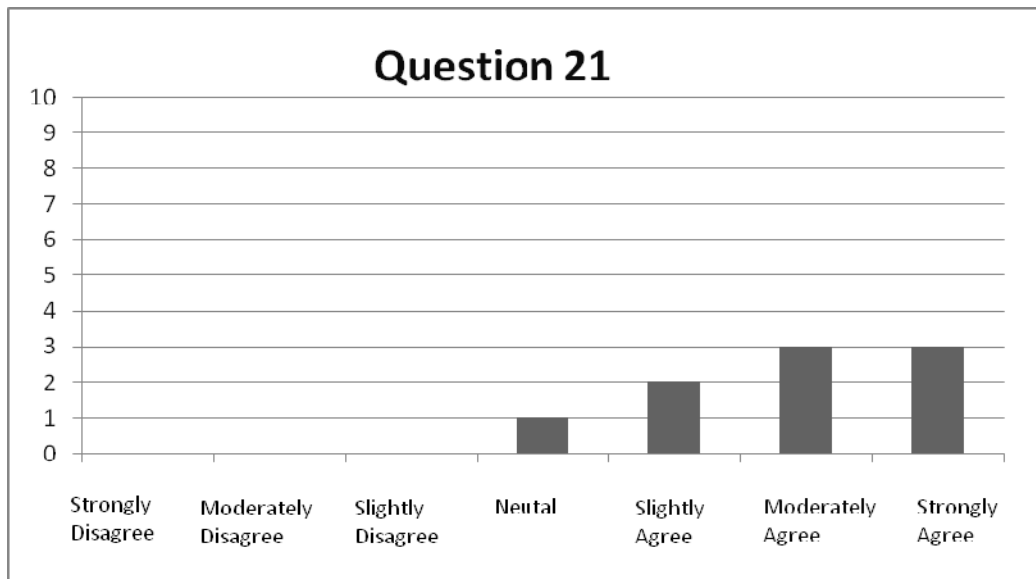


Figure 25. Answers to Question 21

*Question 22:* Without proper training and experience pilots may not be able to handle the vast amount of information provided by the JSF system.

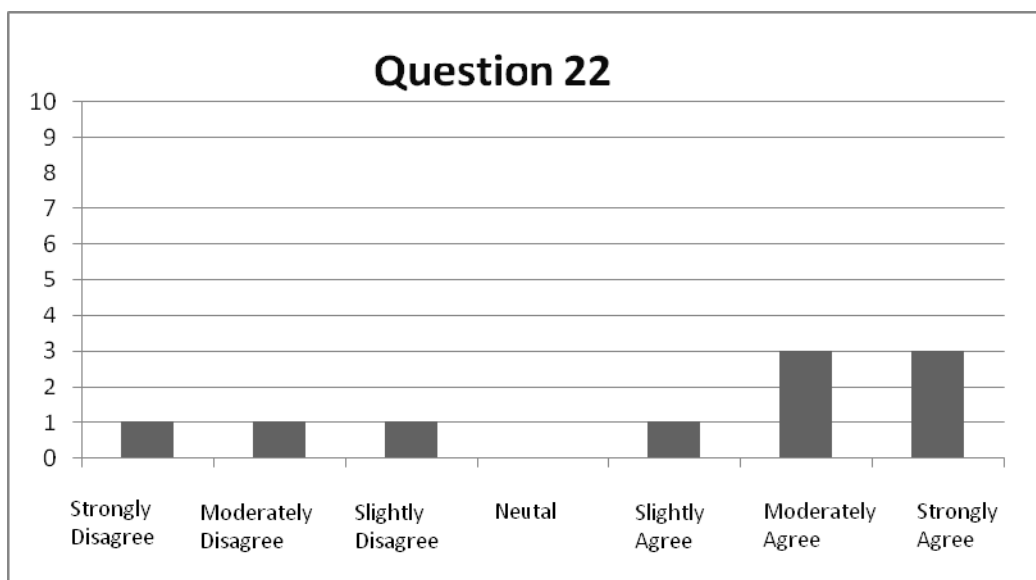


Figure 26. Answers to Question 22

*Question 23:* I believe the main task of the pilot will switch from mostly flying the aircraft to making tactical decisions.

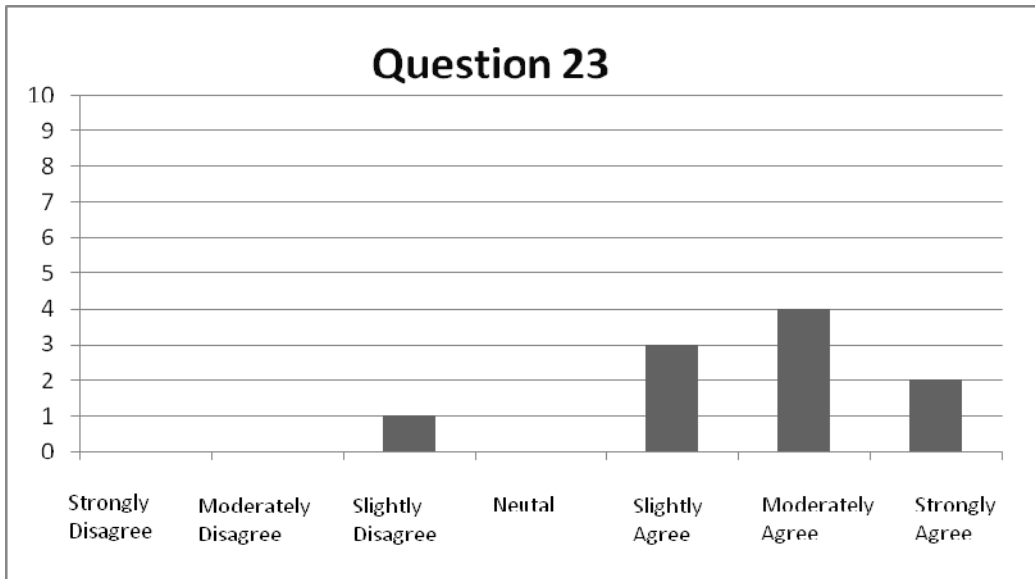


Figure 27. Answers to Question 23

*Question 24:* Being able to follow the whole tactical arena did not affect my focus on my own target/area of interest.

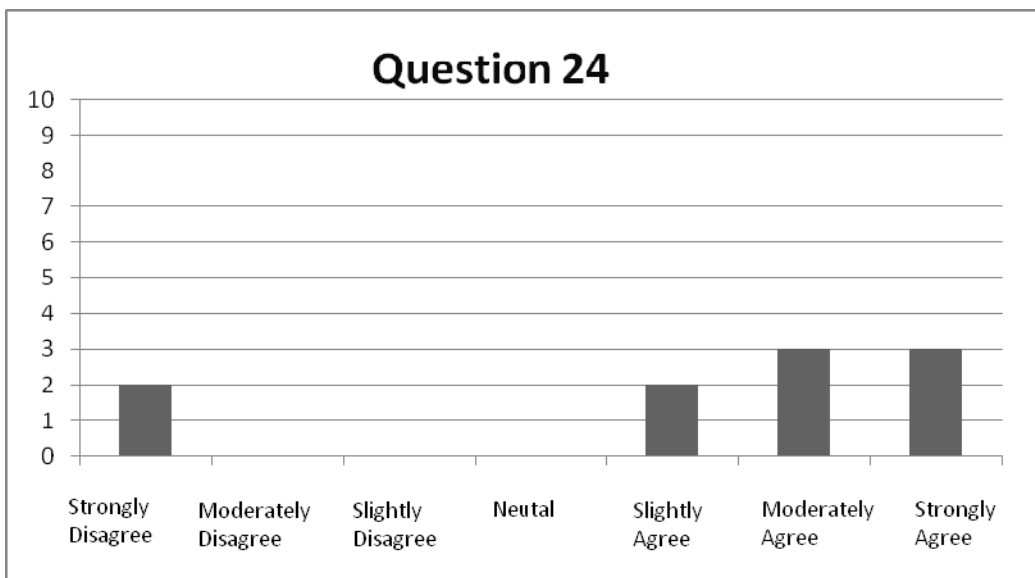


Figure 28. Answers to Question 24

*Question 25:* Managing both A/A and A/G data at the same time will overload pilots under some tactical situations.

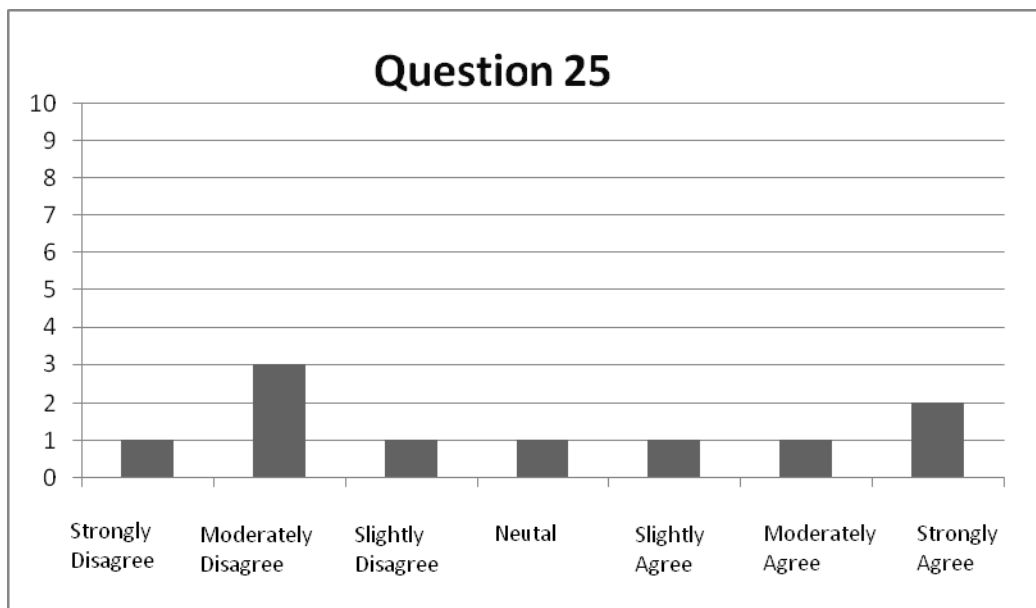


Figure 29. Answers to Question 25

*Question 26:* I felt the need to effectively filter and declutter the presented information in most tactical situations.

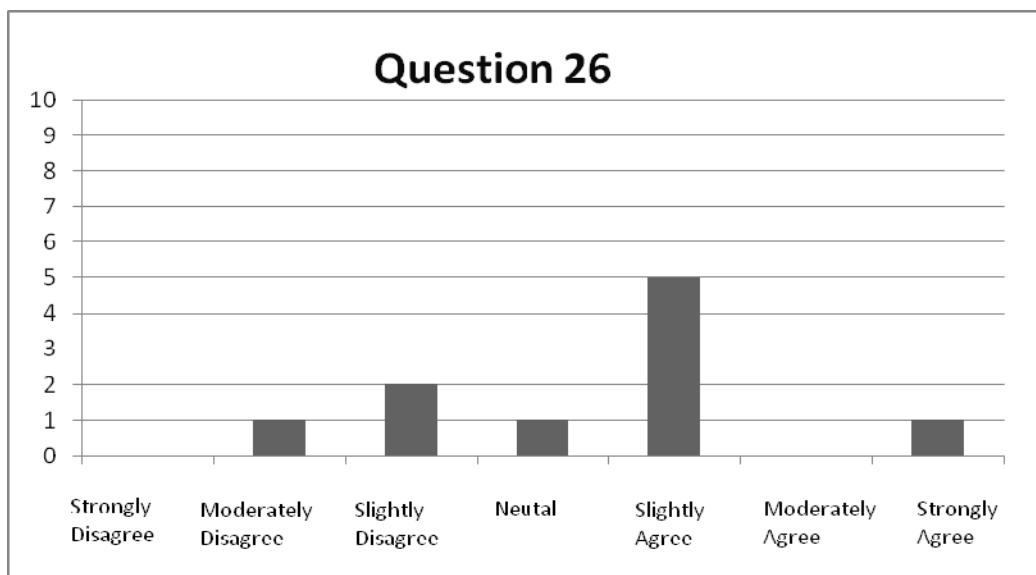


Figure 30. Answers to Question 26

*Question 27:* Even if JSF presents a very good tactical picture, a high level of tactical experience is required to be able to use the capabilities of the aircraft to the utmost extent.

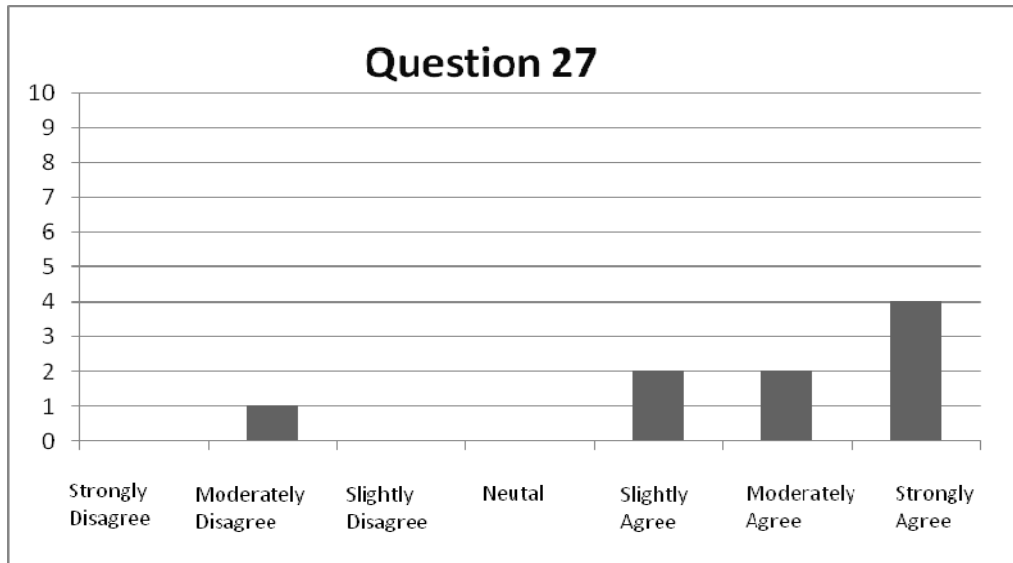


Figure 31. Answers to Question 27

*Question 28:* Compared to my current type of aircraft, the training period should be longer to comprehend the systems thoroughly and fly the aircraft at its capabilities.

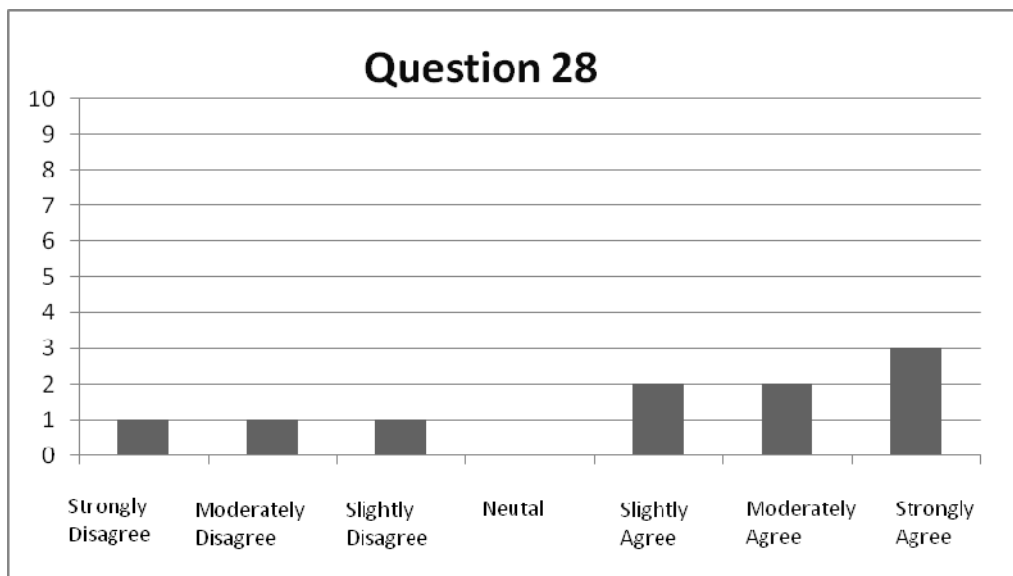


Figure 32. Answers to Question 28

*Question 29:* The new concept of JSF requires building and maintaining better SA and more cognitive workload than my current type of aircraft.

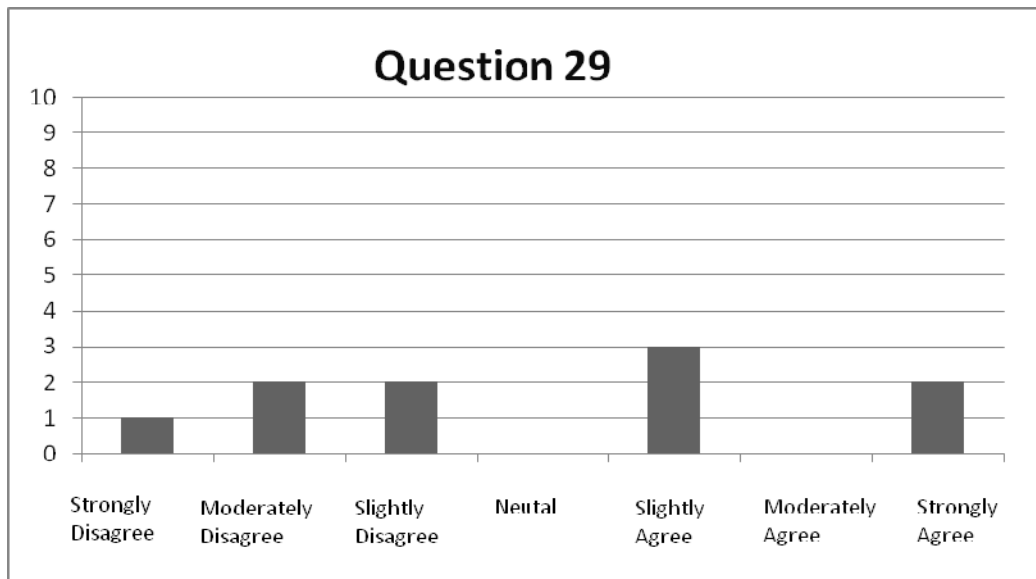


Figure 33. Answers to Question 29

*Question 30:* There were some instances where I had difficulties at shifting my attention between the overall tactical picture and my task related tactical picture.

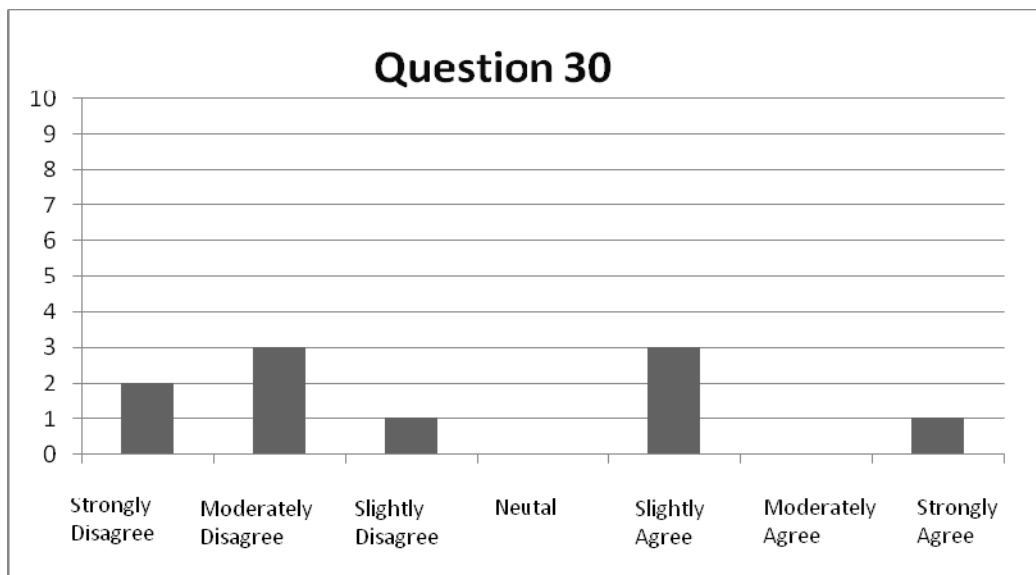


Figure 34. Answers to Question 30

*Question 31:* I believe a longer pre-flight preparation is needed for JSF.

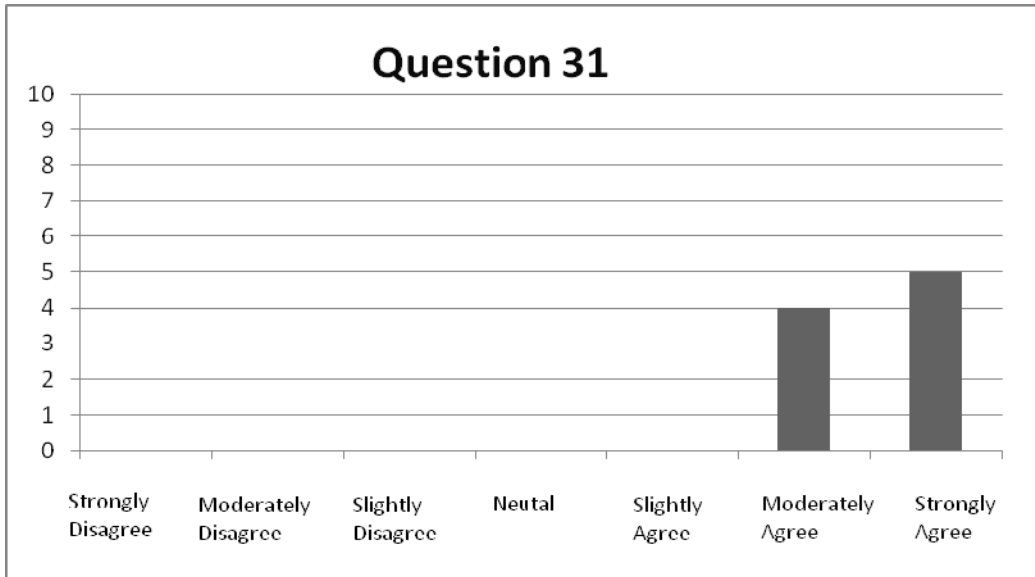


Figure 35. Answers to Question 31

*Question 32:* Even if the systems enhance in-flight mutual support at a great level, formation briefing and coordination are even more critical than for previous types.

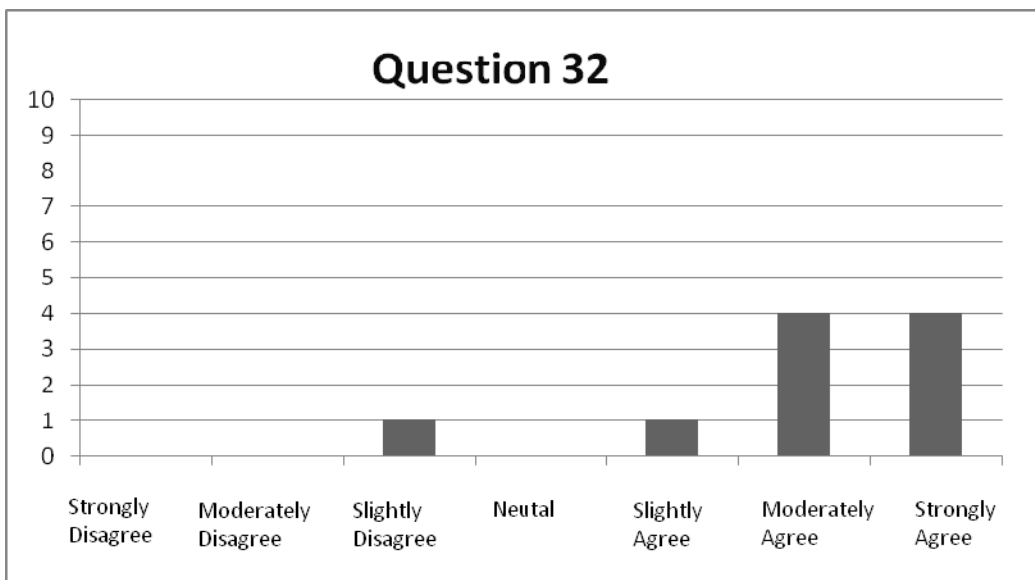


Figure 36. Answers to Question 32

*Question 33:* The simulator flights and real flights should be exactly similar in terms of briefing, mission and debriefing.

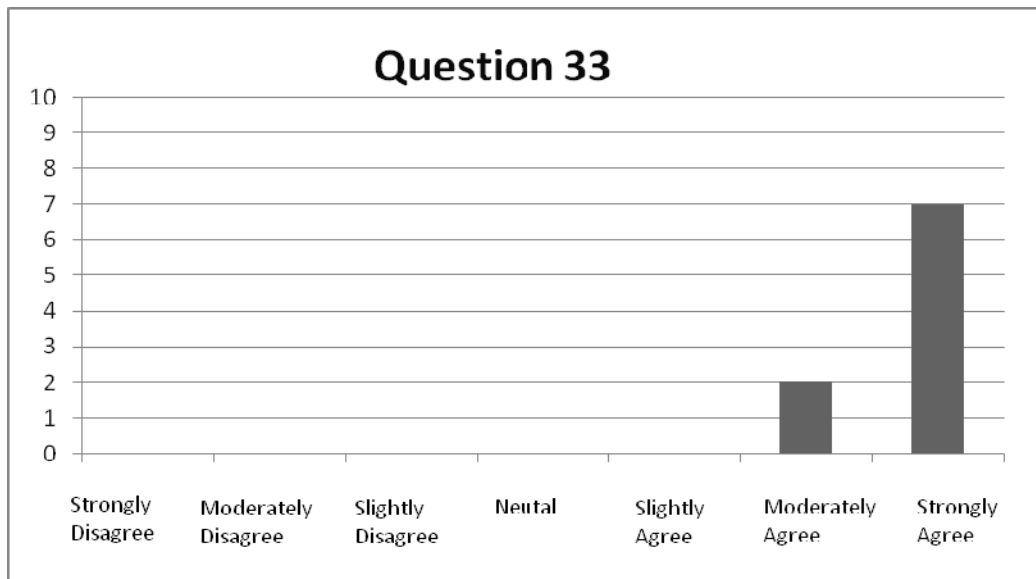


Figure 37. Answers to Question 33

*Question 34:* PC trainers donated with real throttle and stick controls would be significantly beneficial to improve the systems management skills of pilots.

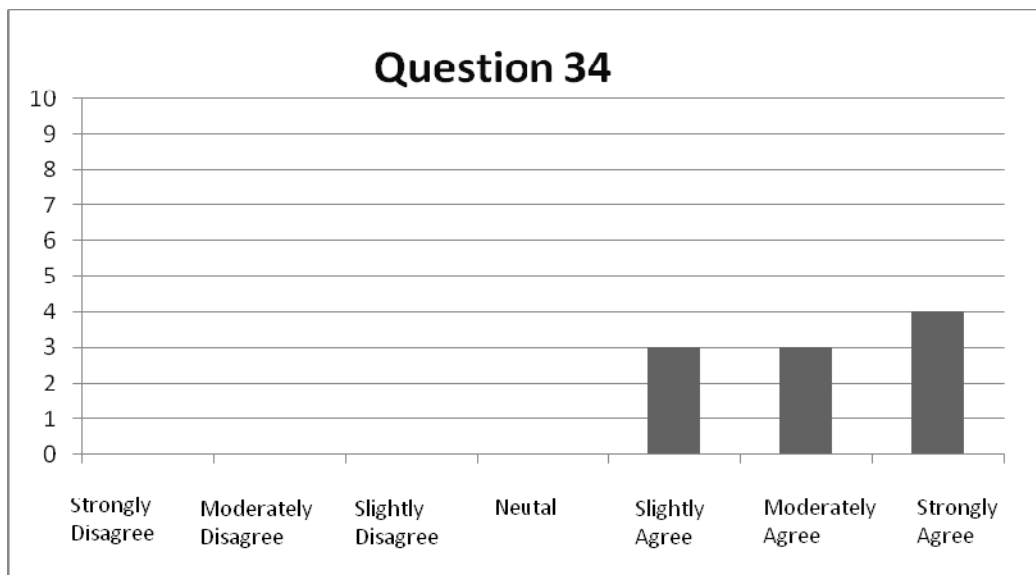


Figure 38. Answers to Question 34

*Question 35:* To improve the pilots' display suite management and tactical picture assessment skills, alternative-training systems on the ground will be helpful other than actual flight conditions.

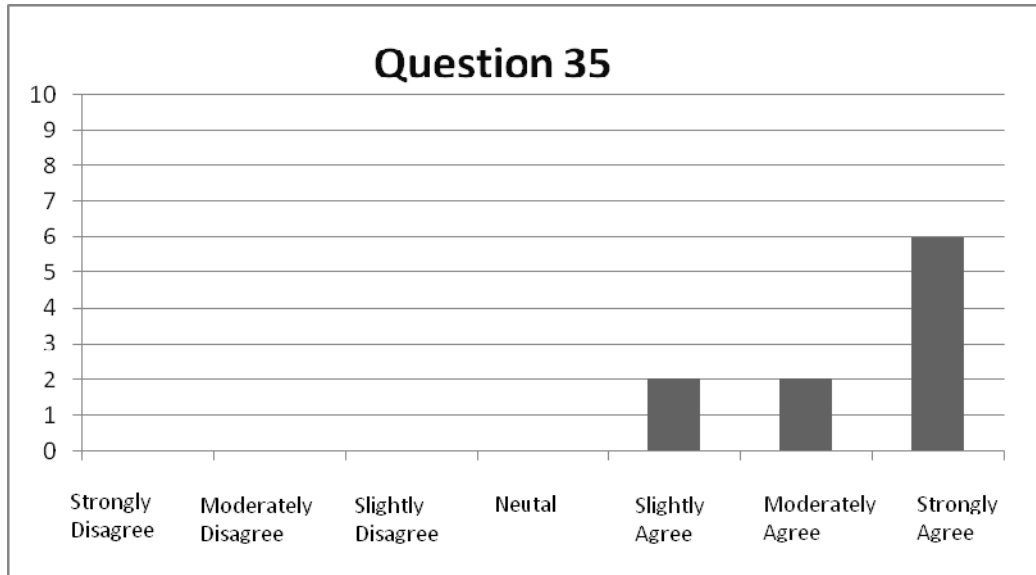


Figure 39. Answers to Question 35

## 2. Open-ended Questions

It is always possible to miss important points in the survey questions. Another possibility is that there are additional aspects that the participants can provide to the argument. Those were the reasons to include the open-ended questions to the follow-on survey, to allow participants to add their opinions and additional comments about transition, training and safety concerns of JSF.

The results are provided again as summaries based on the common answers to each question, as well as some less frequent but interesting ones. Five questions were asked, and the results can be seen below.

*Question 1:* What do you foresee as the most significant problems or training issues? Briefly describe.

Many participants saw the capabilities of JSF as being significantly better than the current types, and that there will be more demand for technical and

tactical knowledge to fly JSF. The JSF will require more resources in training due to its increased capabilities; these will include such things as wider training areas, ground training devices, and many more. Another important common opinion is the importance of the tactical experience, and its currency. The majority of the participants agreed that the transitioning pilots should have tactical experience before JSF in order to fly safer and more efficiently due to its dominating capabilities, and the abundant information it provides.

*Question 2:* Which one of the following pilot types do you think will qualify to effectively and safely fly all the missions with JSF earlier in transition phase: a pilot who gained experience in another aircraft type, or a new graduate pilot from flight school? Why?

There is a solid consensus about this issue, and the participants think that the JSF is relatively intuitive and easy to adapt. It also provides all and maybe more than necessary information to the pilots, with its numerous systems, but they add that it will need experience to filter and evaluate the alternatives, in order to make quick and robust decisions. Thus, they prefer experienced pilots to be sent to JSF.

*Question 3:* What might be the most likely cause for flight safety problems in JSF?

Two agreements emerge from this question. The first one is related to HMD and DAS related disorientation hazards. The pilots think that disorientation is a potential threat, and suggest that operating procedures should be established properly and pilots well trained in those systems' use. The second concern is the display suite with the portals. The participants report that especially in high workload conditions, fixating on the display suite may be a very common and risky concern about flight safety. As almost all of the mission related tactical information is presented on that display, there will be a tendency for the pilots to fixate on it, and be unaware or less aware of other parameters and outside information.

*Question 4:* What would be your recommendations about the transition and training phase of JSF?

The participants see two factors as important in terms of training and transition to JSF. They want the training period to be very intensive, well planned, and also to have ground training devices. The main reason for this kind of intensive training is the extensive capabilities of the systems. The more capable systems require more dynamic training. Another comment the participants make is the importance of employing experienced pilots in the transition periods first, to be followed later by the less experienced pilots.

*Question 5:* Other Comments

No important comments were made for this question.

## **C. DISCUSSION OF THE FINDINGS**

This section is intended to summarize the major points that emerged from the follow-on survey. Detailed answers to the questions can be found in the previous section of this thesis.

This discussion is based on comments and responses by the participants and the opinions of the authors. The discussion of the findings is divided into three topics: cockpit automation, safety concerns, and training transition. This classification is based on the major concerns raised from the answers, but also they reflect the literature review chapter of the thesis. The major arguments about modern cockpits from a human factors perspective also contain the same topics.

As is thoroughly discussed in the related work chapter, automation has had dramatic impacts on the human user's role and responsibilities; the more modern, and complex systems in the cockpits required higher levels of cognitive skills, higher workloads, and higher training requirements. This section will not provide the related literature; for further information the reader can refer to Chapters II and IV.

## **1. Cockpit Automation**

As discussed in Chapter IV, automation is used effectively in commercial aviation, but not yet in military aviation, especially in fighter cockpits. Although many individual systems (such as radars) had automatic features, the autopilot has been rarely used in the military. Especially in dynamic situations, military pilots prefer to have manual control of the aircraft. All these factors have reduced the human factors problems in fighter cockpits so far. But the question of whether this will change in JSF is raised after reviewing the design philosophy of the aircraft. That question required further investigation and was the reason the survey included many questions regarding this concern.

The major finding about this issue is that the participants think the autopilot will be used more than in their current aircraft. Additionally, they agree that the main task of the pilot will shift from actually flying the aircraft to making tactical decisions. These findings show a need to think about the impacts of automation in the JSF cockpit. The problems and hazards found in the literature will probably also be a concern in fighter cockpits beginning with JSF. Considering the riskier, more dynamic and higher workload of fighter missions, there is a need to understand which problems will also be an issue in fighter cockpits and to what extent.

After acknowledging that the autopilot will have more use in the JSF cockpit, the participants add that it will not mean that the basic flying skills will no longer be necessary. The handling and control capabilities are expected still to be important skills.

Another concern raised by the participants is to understand if the autopilot in JSF is considered easy to learn and operate by the pilots, and if the autopilot may cause the pilots to lower their awareness about the task it performs. The main opinion is that it will be easy to learn and operate, and to be aware of the modes of autopilot. At the same time, some participants believe that the use of autopilot may decrease the awareness of the pilots of the parameters it

manages. But they also think that the pilots will be able to overcome any problems about automation or the parameters it controls, too. In conclusion, automated flight features may be easy to learn and operate, but even if there is slight agreement on the decrease in awareness, it is expected that the pilots will be able to overcome any related problems. Considering that the real missions will be more stressful and demanding, the authors think that these concerns about cockpit automation require further research for more precise understanding, and may pose a higher threat than indicated by the participants' expectations.

The last agreement about automation is that it does what is claimed in the JSF cockpit. The participants agree that the autopilot and other automated systems helped them to focus more on the tactical picture. Other important aspects of this finding will be discussed in the next section.

## **2. Tactical Decision Making and Systems Management**

This section contains a wide spectrum of human factors areas, such as SA, workload, spatial disorientation, and cognitive tunneling. Many question were asked about the use of the systems, workload, safety traps, and other potential issues.

One of the objectives of the survey was to capture the opinions of the participants about the usability of the cockpit controls and displays. The concern here is not to capture the workload and stress during the missions, but whether it is easy to operate the systems, such as changing modes, making modifications and managing the menus. There is a general agreement that the operation of the flight management systems is easy. The participants did not find that there were modes that were hard to understand. The participants indicated that it will be easy to learn how to operate those systems and that the management system will probably not be a major problem.

There was no general consensus about whether it will take extra time to learn to effectively operate the controls. However, when the question is related to

the control stick and throttle, and special emphasis is given to the display suite, the participants think that they should be addressed very carefully and focus on using all necessary training equipment.

Both ample information from various sensors, and possible tactical changes in air combat could present higher workloads to pilots. Additionally, the big LCD suite will be the main display while performing tactics in those high workload situations. If the autopilot is also used in these situations, awareness, cognitive tunneling, and other related hazards might be a potential threat. To investigate these types of threats, the survey included two groups of questions.

The first group of questions addressed the concern that the participants had times when they needed to focus, or fixate on the display suite. The opinion is that there is a need for using the display suite in many tactical situations. The participants agreed that there is a reliance on the display suite in general too. It is legitimate to say that there is no doubt in the participants' answers, that the pilots will be using the display suite very frequently in many tactical situations.

After assuming the fact that the pilots will focus mostly on the display suite, the following question is whether it will pose a threat to flight safety. And figuring out this issue was the objective of the second mentioned group of questions. Some of the related answers are that there were instances when the pilots think they focused on the display suite more than they think is safe, and they generally think there is a risk that the pilots will fixate on this display suite and become unaware of other information such as "fuel state", "altitude limitations" and many more. Especially in higher workload situations, the participants report that they needed to focus more on the displays in order to reach and evaluate the tactical information.

According to the participants, the threat mentioned above is obvious, but with the more specific questions about the display suite, there are blurred areas. The authors expected to find data filtering difficulties, but the participants reported that even if there was a great deal of information, they did not have

difficulties in reacting appropriately. Similarly, no significant agreement is reported about the existence of both Air-to-Air and Air-to-Ground symbology at the same time. Roughly, half of the participants report that it may overload the pilots, and the remaining half do not agree. Additionally, they also did not agree clearly on the need to declutter some symbology.

Another controversial issue is whether the pilots will have attentional focus problems due to the fact that they will be presented with a very big picture of the battle area. For instance, a flight leader may be responsible to intercept an enemy formation, but in JSF he will have almost all battlefield information in front of him, such as other friendly assets and both air and ground threats. After a while, he should focus on building intercept geometry, target sorting, and monitoring the target formation in more detail. Whether other “big picture” information will distract him from focusing on his target is an issue. Will the pilot be able to focus his attention back and forth between his targets and the general picture? The participants’ answers reveal that they did not have any difficulty in focusing on their target areas; however, half of them experienced instances where they had difficulties in shifting their attention between the overall tactical picture and their task related picture.

Surprisingly, the participants did not have any major difficulty in filtering the data, managing both Air-to-Air and Air-to-Ground data simultaneously, and operating the display suite. Additionally, they did not report any apparent problems in shifting attentional focus, and they expressed that it was easy to set up and operate the systems. However, when asked whether a high level of tactical experience is required to use the capabilities of JSF to the utmost extent, the participants answered in the affirmative. They had many comments addressing the importance of the tactical experience. The participants agree that filtering and evaluating the data, as well as making quick and proper decisions will require tactical experience. The reason for the contrary aspect can be twofold. Either the participants found the use of the display suite, attentional focus, and data filtering not to be a problem, because they could cope with many

issues, given their experience, or they see the complex cognitive processes while decision making and managing the displays, and processing information, as separate. And they think that while the former task is hard, the second tasks are relatively easier. Either way, the experience factor cannot be denied, but the data filtering and display suite operation in actual missions require further research.

Disorientation and distraction were also the concerns of this thesis. Both are related to the visual systems, especially HMD and DAS, as the authors predicted. The participants do not support the first suspicion of the authors, that the HMD will distract the pilots' attention with the symbology it presents continuously. They report that seeing HMD symbology wherever they look did not distract their attention. But the major potential hazard expected by the participants is the DAS, if the pilot is not trained to use it properly. The participants agree that the DAS may cause disorientation in some conditions. Additionally, most of them mentioned the same risk in their open-ended answers. They also commented that the training and operational procedures of this system should be established very carefully.

### **3. Transition Training**

Among the areas investigated in the survey, the concerns related to training during the transition period showed the strongest agreement among the participants. The survey explored the opinions of the participants about the training in two major topics. In the first one, the systems' training issues are questioned, whereas in the other one, the training system is investigated as a whole.

The systems of interest in this context are HOTAS, the display suite, and DAS. The survey has explicit questions for the first two systems, and the recommendations about DAS training came mostly from the answers related to safety concerns. The reports about DAS are mentioned in the previous section,

and the emerged agreement is that it may be prone to cause disorientation in some conditions, and properly should be addressed during training to mitigate any potential hazard.

The initial thought of the authors was that pilots would need more emphasis on training for HOTAS management. HOTAS is not new to the cockpits and pilots, but the reason is that the JSF has more systems with enhanced capabilities, and thus more switches and menus in HOTAS. Additionally, the pilots may have a higher workload in order to use all capabilities of such an advanced fighter. However, the general opinion of the participants is neutral on the question of whether HOTAS management will demand considerable amounts of experience and training, but they mostly agreed that it will be very useful to have a PC-Trainer type of device with real HOTAS to train pilots about the management of the system. When it comes to the training of the display suite, there is a stronger agreement. The participants mostly agree that special emphasis should be given to display suite management during training. Additionally, evaluating the information from the displays for tactical assessment was also found to be an important training issue, and participants strongly agreed that alternative training devices such as PC-Trainers will be very beneficial for this purpose. Another supporting fact for the opinion of using alternative training devices is that the participants also mentioned it in their open-ended answers. Addressing the same cognitive processes while pilots make complex decisions in very demanding situations during ground training looks to be more important in JSF than in the current types.

Another aspect of interest about the training is the general opinions of the participants. The most general question related to this issue is whether JSF will require a longer training period than the current aircraft to make pilots combat ready. Whereas the general tendency was to agree this statement, three out of ten pilots disagreed. One of the critical factors of the participants' JSF background is that they did not fly missions according to any performance grading criteria, but just experienced various missions and gave feedback. Both

during actual JSF training, exercise and combat missions, the pilots will have real objectives that will be measured objectively. It is highly probably that the more demanding and risky missions could give the participants a better perspective, and they could be able to see the difficulty levels about the tasks better, and more realistically.

While slightly agreeing that JSF should have a longer training period, the participants strongly agree that longer preflight preparation will be needed for JSF missions. Moreover, they also strongly agree that even if the systems enhance mutual support to a large degree, formation briefing and coordination will be even more critical than in current fighters. Another agreement is that the participants think that the simulator missions should be as similar as possible to actual missions. All of the aforementioned strong agreements mean that the participants think the missions in JSF will be more demanding, and thus require longer preparation, more coordination, briefing and more simulator practices. Altogether, these comments indicate a need for longer and more demanding training in JSF.

An interesting point emerged among the answers, in that the participants also agreed about the role shift phenomenon. Some of them commented that the training should focus more on data filtering and decision-making in complex situations skills. These skills are also important for the current types, but with the increasing amount of data, enhanced capabilities, and possibly harder demands during JSF missions, these skills may become more important than before, and should be specifically addressed during the curriculum.

The participants agreed strongly about several aspects of the transition period: The training devices such as simulators and PC-Trainers should be used to the utmost extent; transition pilots should have tactical experience before JSF. The main reason is that the participants think the experience is the crucial factor for evaluating the data, and using it for making tactical decisions in JSF. In order to cope with abundant data, and high workload, the participants think experience is critical. Especially, the consensus is that the first group of transition pilots

should be very carefully selected from among the experienced pilots, and two participants think that the less experienced pilots could be also transitioned directly to JSF after the first group, but with a well researched, and developed instructional curriculum. The participants agree that the pilots should be trained thoroughly for each difficulty during ground training to prepare them to demanding situations during actual missions. The issues include tactical decision-making, using both A-A, and A-G capabilities simultaneously, information reaching and evaluation capabilities, and switchology.

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## **V. CONCLUSIONS AND RECOMMENDATIONS**

### **A. SUMMARY OF KEY FINDINGS**

Although there are more concerns that emerged from the research of this thesis, this chapter will focus on the ones most agreed upon by the participants. Some of these predictions are also strongly supported by the literature. Findings about automation and display suite operations are examples in this category. Other findings cannot be directly found in the literature, but not because they do not have scientific support. The main reason is that they are related to the new systems in the cockpits such as DAS. Although there are many studies about HUD and HMD, the DAS has many unique capabilities that prevent using the findings of HUD and HMD to solve the potential problems in DAS. The potential concerns are given in a summary sentence format; for more detail, the previous chapter will provide enough information.

#### **1. Increasing Use of Autopilot**

The need to use the autopilot at a significantly increasing level is one of the findings of the follow-on survey. The participants also acknowledged the role shift of the pilot due to increased automation. Even though participants did not directly point out a problem related to mode or system awareness during simulator missions, the authors believe that the findings in the literature about increasing autopilot use will be valid and applicable to JSF. Most of the studies in the literature examined autopilot use in commercial aircraft. Even though the tasks and required pilot skills vary from commercial cockpits to fighter cockpits, the common human factors issues also will be experienced in the JSF cockpit. The JSF pilot will have more tasks at hand, that are to be accomplished in a much more stressful environment, and with greater demand on cognitive resources; thus, the authors predict that JSF pilots will also be prone to automation-related human factors concerns.

## **2. HMD and DAS Usage**

Throughout aviation history, it has been frequently observed that while technology and inventions solve the current problems, they also give rise to new human factors concerns. DAS represents a totally new concept in the fighter cockpit, and the participants strongly agree that it may cause disorientation in some cases. They think that the operational procedures and DAS usage in different environmental and meteorological conditions should be thoroughly examined and addressed in pilot training.

## **3. Display Suite Management**

The display suite in JSF is the most noticeable component of the cockpit. This display will be the prominent PVI element during flights, where the pilot can reach all the sensor data and interact with the systems as required. The features of the previous aircraft displays are combined into this display in JSF, thus making the display more appealing and prone to visual and cognitive tunneling issues as seen in the literature. The participants also agree that this display suite may cause cognitive tunneling, and fixation issues during operations.

## **4. Tactical Experience and Decision Making**

The participants strongly agreed that tactical experience is one of the most vital features for a pilot to make the most out of the systems in JSF. Even though filtering the data from various sensors is not thought to be difficult by the participants, assessing this data in order to make demanding tactical decisions will require significant tactical experience. Considering the changing mission concept of JSF, combined Air-to-Air and Air-to-Ground data, and new systems, the authors agree with participants on the importance of tactical experience. Dealing with more systems and data with the same attentional resources will be one of the crucial aspects of the required skills in JSF. The participants not only stated the importance of tactical experience in regular missions, but also during transition and follow-on training phases.

## **B. TRAINING OBJECTIVES**

After identification of the major concerns, there is a need to address them during training and while establishing operational procedures of the aircraft. These two processes are closely related; if there is an operational procedure, the system trains the trainees to accomplish that procedure. This section includes the training objectives that are thought to mitigate any potential problem related to the identified concerns. The training objectives are created to meet the common problems found by the literature, and predicted by this study. The training objectives do not cover all of the required objectives related to each predicted concern, but just the major findings of this thesis.

### **1. Increasing Use of Autopilot**

- The pilots should have a thorough understanding of the automation technical data, operation and modes, and their interactions with other systems.
- The pilots should perceive automation as another important system of the aircraft and build skills for robust coordination and operation.
- The pilots should be aware of the tasks performed by autopilot and autopilot modes continuously, even under high workload conditions.
- The pilots should also be able to solve the emergency situations related to automation malfunctions and while automation controls the parameters.

### **2. HMD and DAS Usage**

- The pilots should build robust mental models of HMD and DAS and their operational procedures.

- The pilots should be ready to accomplish their tasks during HMD failure successfully and they should cross check the parameters shown in HMD with Head-Down indications as required. They should not over trust the HMD.
- The pilots should learn to transition safely back and forth between Head-Up and Head-Down operations. In addition to Head-Up to Head-Down transitions, the DAS transitions are predicted to be critical phases of the flight. The pilots will “see through” the fuselage and look for targets of interest under the aircraft, etc., and then they will have to transition back to the normal vision or vice versa. Problems such as disorientation and attentional shift are predicted, especially when these transitions happen during high workload, adverse weather, and other demanding situations. The pilots should be able to use, and transition to or from the DAS safely. Another aspect of this issue is the need for well-defined operational procedures that will enable the pilots to comprehend the current situation, and make proper assessments depending on the operational procedures.

### **3. Display Suite Management**

- The pilots should acquire full knowledge about the display suite. The raw technical information, modes, and menus of the portals, meanings of the symbology, and the required skills for operational procedures are among the important aspects related to the display suite management.
- The pilots should be able to setup, operate and modify the portals effectively according to the mission requirements.
- The pilots should cross check the data shown with various sensors if possible, and be able to anticipate any problems about the symbology and presented information.

- The pilots should be ready to accomplish their tasks successfully during display or portal failure.
- The pilots should not fixate on the display even under high workload tactical situations, and should also be aware of other parameters.
- The pilots should build comprehensive knowledge about the interactions and cooperation among the systems feeding the display suite. In case of a failure of any of those systems, the pilots should be aware of the reliability of the information at hand and make correct decisions in these contingency situations.

#### **4. Tactical Experience and Decision Making**

- The pilots should be proficient enough to filter the unnecessary data easily, and to locate the required information in the tactical displays.
- The pilots should be able to process and evaluate the presented data quickly and accurately.
- The pilots should have proper prioritization and attention allocation skills and techniques for highly demanding and high workload situations.
- The capable and modern sensors will flood the pilots with a great deal of information, and it is likely that the pilots will experience many situations that are complex, hard to analyze, and in which it is hard to make proper decisions. The pilots should be capable of making quick and accurate decisions under such complex scenarios.

## **C. GENERAL TRAINING GUIDE**

The predictions of this thesis are parallel to the research literature. Important aspects of modern glass cockpit aircraft are generally similar in terms of the human factors perspective. Increasing automation, LCD or MFD displays, increasing sensors with enhanced capabilities—all present new challenges to pilots. Thus, the authors think that the solutions proposed in the literature will also be applicable to the JSF case. The limitations explained in previous chapters prevented conduct of actual experiments; therefore, the basis for this chapter is the research literature, participants' comments and the experience of the authors.

### **1. Increasing Use of Autopilot**

*Objective 1.1 The pilots should have a thorough understanding of the automation technical data, operation and modes, and its interactions with other systems.*

*Objective 1.2 The pilots should perceive automation as another important system of the aircraft, and build skills for robust coordination and operation.*

One of the findings supporting the importance of these objectives is that Sarter (2000) reports that pilots do not have a through understanding of the structure and operational procedures of automated systems.

Rigner and Dekker (2000) are among the researchers proposing incorporation into pilot training of a curriculum dedicated to automation. They note that automation training is given in transition training today, and shifting that to earlier fundamental training may be a better approach.

Rigner and Dekker (2000) also observed that the content of the current automation training is incomplete. The training is more based on general technical information about the automated systems and very limited scenarios. They claimed that automation should be introduced and taught as a team

member of the cockpit rather than a subsystem of the cockpit systems. This is the case in most of the phases of flight, and autopilots make decisions and give inputs as the pilots do.

Casner (2003) claimed that almost all current aircraft benefit from automation, and that this topic can therefore be addressed in basic flight training. This stage is where pilot trainees get their introduction to general topics about aviation such as weather, aerodynamics, flight rules and many others. They are not assigned to their final aircraft type yet, and usually fly their first aircraft in their careers. However, this is a suitable time to train them about the fundamentals of cockpit automation. Currently, the automation training varies from type to type.

To study the subject further, Casner (2003) conducted an experiment to measure the effectiveness of such a curriculum. In addition to a control group, the target group received the aforementioned training in a small aircraft cockpit, and the target group demonstrated positive training transfer in their second trials in a commercial aircraft's simulator while performing automation-related tasks.

The fighter pilots scheduled to fly JSF should be trained on the fundamentals of automated systems, and especially autopilots in their initial pilot training, and then build their professional skills with their aircraft-specific type trainings. Where this solution is not applicable, this training can be implemented within the JSF training itself. Either the fundamentals and basic principals may be given before proceeding with the training of automated systems of JSF, or they may be directly integrated to JSF autopilot systems training. At a first glance, the second way sounds more practical, but further research is required in order to figure out the better way scientifically. The objective of this change is to provide pilots better background about cockpit automation, and thus help them build more robust mental models about all automated systems in the JSF cockpits. During this training phase, another important objective should be to help pilots build robust perception about the autopilot. Considering that the pilots may use the autopilot in demanding situations, it is crucial to give them the required skills for effective cooperation. The pilots should be directed to not perceive the

autopilot as a “fire and forget” system, but rather as a separate system to be cooperated with, and checked for proper operation when necessary. The recommended topics for the automation ground training for JSF pilots are as follows:

Recommended Initial Automation Training Topics

- The Basic Structure and Principals of Autopilot Systems
- Common Problems Found by Literature Concerning Cockpit Automation
- The Interactions and Interrelations between the Autopilot and Other Systems in JSF
- System Analysis and Problem Solving of Automation in JSF
- Analysis of the Autopilot Modes in JSF and Potential Threats During Missions
- Pilot-Autopilot Cooperation Procedures

*Objective 1.3 The pilots should be aware of the tasks performed by autopilot and autopilot modes continuously, even under high workload conditions.*

*Objective 1.4 The pilots should be able to solve the emergency situations related to automation malfunctions and while automation controls the parameters.*

The findings of Sarter and Woods (1994) supported the common fact about pilots on automation. They report that pilots were comfortable in performing the standard basic tasks in cockpits such as “intercepting a radial, building or executing a holding pattern...,” but they experienced difficulties during the tasks requiring comprehensive understanding about automation such as “aborting a takeoff at 40 kts with autothrottles on” and “...anticipating when go-around mode becomes armed through landing...” (p. 14).

Similarly, the findings of Sarter, Mumaw, and Wickens (2007) were also consistent with the previous studies. During their research, both with subjective and objective measures, the pilots allocated considerably more of their attentional resources on basic flight parameters than on the automated systems. Their automation awareness was much lower than their general awareness, and one of the reasons was reported as improper mental models about the automation.

There are two major points related to Objectives 3 and 4: the awareness problem, and the lack of skills to solve complex situations. A broader discussion about the decision-making skills in complex situations will be given in the Tactical Experience section of this chapter, and the emergency situation solving skills about the automation are the major concern about the automation training objectives.

The recommendations concerning the above issues are as follows:

#### Increasing the Awareness and Enhancing The Complex Problem Solving Skills of Pilots about Cockpit Automation

- Develop the Operational Procedures so that they make sure the pilots also control the automation-related parameters and modes as they do with other flight parameters.
- Ensure that pilots acquire those skills mentioned above during ground training, especially in simulator missions; set sortie objectives related to the awareness of automation in JSF cockpit.
- In simulator missions, stress the emergency solving capabilities of pilots in two conditions: the autopilot is controlling some parameters, and any other system failed, causing an emergency situations, or again the autopilot is controlling some parameters, and it itself fails causing an emergency situation. Inject these kinds of events to the simulator missions also under high workload situations, while pilots are busy with tactical decisions, and tend to forget to check what the autopilot is doing.

## **2. HMD and DAS Usage**

The results of both interviews and surveys do not indicate any major problem with HMD use. In contrast, the situation changes with DAS and the participants agree that DAS operational procedures, and training curriculum should be specifically established in order to mitigate any disorientation or attentional focus concerns. Even though there have been many studies conducted about the HMD and HUD in fighter cockpits, the DAS is a brand new system. The authors were not able to locate any studies about DAS use in cockpits; thus, the predictions by the participants are the main resource to anticipate any problems, as well as to propose solutions.

The training objectives regarding HMD use mostly address the effectiveness issues, but the DAS training objectives are more related to flight safety; thus, they are more critical.

*Objective 2.1 The pilots should build robust mental models of HMD and DAS, and their operational procedures.*

Because the DAS is a new system, there is no coverage of related systems in basic flight training to provide a framework for the JSF pilots' DAS training. Pilots do not need deep knowledge of the technological aspect of DAS, but the focus is more on the operational procedures. The operational procedures and the safety concerns with DAS should be analyzed in high detail. This is the first step by the instructional designers and the frontiers of the JSF before it finds its way to air forces. Then, the second important step is the training of the pilots. Given the fact that their experiences will not include a system similar to DAS, they should be all trained about the anticipated safety issues such as transitions back and forth in adverse weather conditions, and the normal procedures. The objective with these training topics is to prevent any mishaps that could happen because the pilots do not follow the operational procedures or use DAS in conditions where they should not use it. They also should be trained about the

scientific fundamentals of disorientation or attentional focus problems possible with DAS use. Recommendations are as follows:

The Recommended Topics About Das Ground Training

- The Capabilities and Limitations of DAS
- Emphasis on the Standard Operational Procedures
- Human Factors Concerns and Potential Threats About DAS (Disorientation, Attentional Focus)
- The Use of DAS in Adverse Conditions
- DAS Emergency and Recovery Procedures

*Objective 2.2 The pilots should be ready to successfully accomplish their tasks during HMD failure, and they should cross check the parameters shown in HMD with Head-Down indications as required. They should not over trust the HMD.*

One of the important projections of this study is the potential effect of HMD on mission efficiency. The HMD is predicted to be very helpful to the pilots during their missions. Thus, there may be a risk to over trust the HMD and the pilots may choose to accomplish their missions using the HMD more than they should. There are two crucial points about this concern. The first one is that the pilots may not crosscheck HMD indications with the Head-Down displays. This is a common error in current fighters. The pilots are instructed to use the Head-Down displays as their main displays and crosscheck the HUD or HMDs with Head-Down displays while they shift their focus to HUD or HMD. The authors do not have the technical information about the HMD system of JSF. Unless the designers eliminated any possibility that the HMD can display different information than the Head-Down displays, this issue will continue to be crucial in terms of efficiency and flight safety.

The second important aspect is the skills of the pilots. While over-using HMD, they may degrade their capabilities to accomplish their missions using

other displays or systems, and in case of a HMD failure, their efficiency may be affected dramatically. Unless the operational procedures will dictate aborting the missions in case of HMD failure, this will also be one of the important training objectives. Below are the recommendations for these purposes.

#### Enhancing the Awareness and Atypical Operational Skills of Pilots about HMD

- Inject Events of Partial HMD or HMD Symbology Failures Requiring a Crosscheck With Head Down Instruments To Resolve.
- Inject events of Total HMD Failure and Train Pilots to Accomplish All Mission Types Allowed in SOP.

*Objective 2.3 The pilots should acquire the capability to transition safely back and forth between Head-Up and Head-Down operations.*

Other than Head-Up to Head-Down transitions, the DAS transitions also are predicted to be critical phases of the flight. The pilots will “see through” the fuselage and look for targets of interest under the aircraft, etc., and then they will have to transition back to normal vision or vice versa. Problems such as disorientation or attentional shift concerns are predicted, while these transitions happen during high workload, adverse weather, and many other demanding situations. The pilots should be able to use, and transition to or from the DAS safely. Another aspect of this issue is well-defined operational procedures that will enable the pilots to comprehend the current situation, and make proper assessments depending on the operational procedures.

#### Preparing the Pilots for DAS Transitions and Use

- Present demo situations concerning use or non-use of DAS, and observe that the pilots make proper decisions of when to use or not use the system.

- Inject high workload scenarios requiring the use of DAS, and observe that the pilots totally follow the SOP and checklist items while using HD and DAS.
- Train pilots for adverse weather and many other demanding situations of DAS use..
- Train pilots for recoveries after the problems caused by improper DAS use, such as disorientation and attentional shift/focus problems.

### **3. Display Suite Management**

*Objective 3.1 The pilots should acquire full knowledge about the display suite. The raw technical information, modes, and menus of the portals, meanings of symbology, and the required skills for operational procedures are among the important aspects related to the display suite management.*

*Objective 3.2 The pilots should be able to setup, operate and modify the portals effectively according to the mission requirements.*

*Objective 3.3 The pilots should cross check the data shown with various sensors if possible, and be able to anticipate any problems about the symbology and presented information.*

*Objective 3.4 The pilots should be ready to accomplish their tasks successfully during display or portal failure.*

*Objective 3.5 The pilots should not fixate on the display even under high workload tactical situations and should also be aware of other parameters.*

*Objective 3.6 The pilots should build comprehensive knowledge about the interactions and cooperation among the systems feeding the display suite. In case of a failure of any of those systems, the pilots should be aware of the reliability of the information at hand and make correct decisions in these contingency situations.*

The aim of the training objectives of this section is the technological knowledge and operational capabilities related to the display suite. How to use it in demanding tactical situations and the decision-making processes are addressed in the following chapter. There are two driving facts that make the display suite a crucial system in JSF. First, it will be the main interface while operating JSF systems. Almost all required tactical data are fused and presented in this display. And the other point is about a safety concern directly related to the aforementioned fact. The participants foresee a potential threat of fixation on the display suite during operations.

Display suite management is also one of the concerns of the design team. Adams (2007) made interviews with the design officials in the JSF project and they confirmed that the display suite as one large LCD screen instead of the older display systems is one of the important innovations in the JSF cockpit. The need of addressing how to manage this display suite is also one of the training objectives of the design team, and a PC Trainer system is developed for this purpose.

If pilots can increase their proficiency and speed in managing the display suite, it will free their valuable cognitive resources during high workload situations. They will be able to focus on the decision-making processes and how to acquire the important data quickly, but not how to operate the display management system. Below are the recommendations for the objectives related to display suite management.

- Train the pilots in display suite management until they become proficient, even under high workload conditions while operating the display suite.
- Make sure that the pilots totally understand the menus and the symbology of the portals.
- Train to setup the display suite properly depending on the dynamic mission requirements, and ask for mission critical data in high informational overload and high workload conditions.

- Train the pilots to crosscheck the presented data from redundant sensors.
- Train pilots for display malfunctions and make sure that they are capable of accomplishing the allowed mission types under these abnormal conditions.

#### **4. Tactical Experience and Decision Making**

*Objective 4.1 The pilots should be proficient enough to filter the unnecessary data easily, and obtain the required information from the tactical displays.*

*Objective 4.2 The pilots should be able to process and evaluate the presented data quickly and properly.*

*Objective 4.3. The pilots should have proper prioritization and attention allocation skills, and techniques for highly demanding and high workload situations.*

*Objective 4.4 The modern sensors will overload the pilots with too much information, and it is likely that the pilots will experience many situations that are complex and hard to analyze, and for which it will be hard to make proper decisions. The pilots should have the capability to make quick and proper decisions under such complex scenarios.*

Objective 4.1 is mainly covered in the previous section, but it is also related to this section in terms of experience. It also takes experience to know where to look in order to find data. Expert pilots know where to look and when, and easily access required information with less effort. The prioritization capabilities, filtering and evaluating the data, attentional allocation, and decision making under high informational and stress load are all interrelated. This is the reason to keep and analyze all of the objectives together to propose solutions.

The important finding of the FAA research, as perceived by these authors, about flight training that is reviewed in Chapter III is that shifting the curricula to a more SBT orientation, with real consequences in order to address the complex

decision-making capabilities, has the potential of providing the trainees enhanced cognitive capabilities they will require during their demanding tasks in their modern cockpits (Fiduccia et al., 2003; French et al., 2005; Robertson et al., 2006; Dornan et al., 2007). Considering the finding that the participants strongly agree on the importance of the tactical experience in JSF, the decision-making mechanism of the experts also emerges as crucial for JSF pilots.

The recommendations about the tactical experience and decision-making in JSF are as follows:

### **Recommendations for Decision Making and Acquiring Tactical Experience Faster**

- Present pilots with tactical pictures on the ground and ask for specific decisions. This can be accomplished both by using static pictures of the displays or simulator and desktop trainers.
- Various demanding tactical pictures along with critical decisions can be discussed in classrooms.
- Inject high workload into the mission scenarios and train pilots on fixation issues.
- Train pilots for proper prioritization and attentional allocation skills depending on the mission demands, task at hand, and workload. Inject various demanding tactical scenarios to observe proper skills by the trainees.
- The terminology used during the mission communications, how to operate the displays, filter, acquire the data, and making decisions are considered to be taught via simulators and desktop trainers with HOTAS; thus, missions such as BVR engagements, SEAD, and many more can be taught on the ground. The pilots will struggle less with the terminology, display management, and decision-making in the air after such training with effective debriefings. And their tactical experience will build up earlier.

## **D. CONCLUSIONS**

Throughout the thesis research, the authors always aimed to both identify and solve the potential human factors issues in JSF. Although the initial thesis plan was built around the potential NTT issues during transition periods only, the initial and follow-on surveys did not predict it as an issue.

The potential concerns identified by this thesis are: the possible problems during the use of automation, potential disorientation concerns in DAS use, display suite management, and complex cognitive skills required both for tactical decision-making and information management processes.

The research literature review, subjective reports by the participants and the operational experience of these authors formed the basis for the recommendations on pilot training in JSF. A curriculum revision from the traditional training curriculums is recommended to address both the potential automation-related problems and to ensure that the pilots build relevant cognitive skills, by utilizing the ground training devices as much as possible.

## **E. FUTURE RESEARCH RECOMMENDATIONS**

One of the two objectives of this thesis is to identify the human factors concerns in JSF, and the other is to develop recommendations for training to solve the concerns. In the follow-on survey analysis chapter, the shortcomings of the survey were provided, but there remain many other methods for problem identification and solution creations. The aim of this chapter is to provide the framework for possible future research for both processes.

### **1. Problem Identification**

The most important phase of problem solution is to understand the situation first. If this step is not totally fulfilled, one cannot propose robust solutions. This thesis only had the opportunity to benefit from limited resources for a subjective method for problem identification, and what could be done in order to have a better subjective research is briefly discussed in Chapter V.

**a. Research Recommendations**

- In all probability, there are ongoing analyses and surveys at Lockheed Martin about usability, workload, and many other concerns, as well as their solutions related to human factors concerns in JSF. The decision-making skills of the test pilots may be captured in highly demanding complex situations, and other than establishing SOP, normal, and emergency operational procedures. These skills may be imported to JSF training. This thesis both supports the ongoing studies and provides new insights on them.
- JSF will be flown in many allied countries. Each country may have differences in terms of pilot training, and subjective studies may be conducted in order to identify various concerns depending on the countries or types of aircraft. This research will yield different results depending on the background; thus, the training curriculums can be tailored to specific needs if necessary.
- The pilots with experience with the JSF simulator, desktop trainer or actual aircraft may be also surveyed for their training recommendations to identified problems.

**2. Objective Methods**

Another methodology is the objective research. Many experimental designs could serve this objective, but the limitations prevented these authors from getting access to any JSF trainer or simulator in order to conduct an experiment. The design team, and many other frontier officials already are involved with this objective, but because of the security issues, the authors do not have robust knowledge what has been done. But one important fact is that only the design team, JSF program officials, and those researchers having access can do these experimental studies.

The authors do not have enough knowledge about the capabilities of the actual aircraft, full mission simulator, part task trainers, or desktop trainers in terms of conducting an experiment; thus, it would not be legitimate to propose an experimental design. The recommendations below are only suggested as the framework for possible experiments for further research.

**a.      *Recommendations for Experimental Research***

- All of the findings of this thesis, or any other research related to JSF pilot concerns, can be evaluated using various methods, such as simulation.
- For automation findings, scenarios with various mission requirements, informational overload, and workload level can be injected into controlled scenarios and while accomplishing the tasks; the awareness levels of pilots with automated variables can be measured. Also, demanding atypical procedures can be injected into experimental scenarios to measure the participants' complex decision making skills about automation; thus, it can be determined whether their mental models are good enough. The second step after these experiments would be testing the solutions. After establishing proper operational procedures to address the problems, and providing the appropriate training, similar experiments would serve also for testing whether the training is effective or not. A control group with no training, and other groups with other types of training will be beneficial to understanding further the effectiveness of the proposed training solutions.
- For DAS use, the experiments depend on the simulator capabilities. The required extent for motion, and visual cues to create situations to the real aircraft are crucial in order to conduct an experiment on the ground. That has to be validated by the test pilots, or any other source as possible. If the simulators are good enough, various

scenarios in day and night conditions, and in adverse weather conditions with dynamic maneuvers should be constructed where the DAS use is either a choice or mandatory. If the situation requires a choice, whether the pilots face difficulties as predicted or not can be tested. And if the use is mandatory by mission requirements, the situations prone to mishaps can be also identified objectively. The following step would be to test the training solutions. Similar scenarios can be constructed for trained pilots in order to measure their performance, making sure that the issues are addressed effectively.

- For display management and tactical decision making capabilities, two important questions are whether the pilots could build experience with ground training devices effectively or not, and whether proposed newer learning curriculums will help pilots with their complex decision making skills or not. For the second question, a group with similar training as F-16, F-15, or many other current type-training curricula can be used, and the JSF group will be trained with the proposed curricula. The differences can be tested both with decision-making scenarios, where the pilots are asked to make decisions to given problems. Informational overload also can be evaluated.
- Other than the decision making process, the effect of training devices on tactical experience is also an important question. The main idea is that the experts make quick and proper decisions with less effort from their experiences. The end-result of this phenomenon is that if a pilot makes a decision fast and properly, and understands the current tactical situation easily, it can be claimed that he has enough tactical capability. Two groups could be used to measure this question, one group with proposed curriculum, using training devices for tactical scenarios as

explained in training recommendations section, and the second group with a traditional training curriculum. Both groups' performance can be measured during actual tactical missions, and either the elapsed time until a certain goal can be measured, or at a certain time the performance differences can be measured.

It is certain that many of these recommendations have been considered and many others are implemented by the officials in the JSF project, but research from various sources is helpful to increase confidence, or to gain more insight into the situations. Also, many important points are expected to emerge after the aircraft begins to fly in the air forces, but the goal for researchers and related officials should be to predict actual problems in advance, and solve them prior to use.

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## LIST OF REFERENCES

- Adams, R. (2007). Fighters on the horizon. *Military Simulation & Training*, 1, 12-14.
- Alexander, A. L., & Nygren, T. E. (2000). *Examining the relationship between mental workload and situation awareness in a simulated air combat task*. (No. AFRL-HE-WP-TR-2000-0094)
- Berg, S.M. van den. (2002). Prospective memory - From intention to action, Ph.D. Thesis. Technische Universiteit Eindhoven, The Netherlands, ISBN 90-386-1907-3.
- Bjorklund, C. M., Alfredson, J., & Dekker, S. W. A. (2006). Mode monitoring and call-outs: An eye-tracking study of two-crew automated flight deck operations. *The International Journal of Aviation Psychology*, 16(3), 263-275.
- Bohnen, H. G. M., & De Reus, A. J. C. (2004). Pilot workload prediction: Number of display elements (NUDES) as a predictor. Daytona Beach, Florida.
- Boldovici, J. A. (1987). Measuring transfer in military settings. In S. M. Cormier, & J. D. Hagman (Eds.), *Transfer of learning: Contemporary research and applications* (pp. 239-260). San Diego: Academic Press.
- Casner, S. M. (2003). Learning about cockpit automation: From piston trainer to modern jet transport. *12th International Symposium on Aviation Psychology*, Dayton, OH.
- Dalcher, D. (2007). Why the pilot cannot be blamed: A cautionary note about excessive reliance on technology. *International Journal of Risk Assessment and Management*, 7(3), 350-366.
- Damos, D.L., Tabachnick, B.G. (2001). *Cockpit Task Prioritization: Jumpseat observations (Report)*. Damos Research Associates.
- Davies, D. R., & Parasuraman, R. (1982). The practical significance of vigilance research. *The Psychology of Vigilance* (pp. 208-227). New York: Academic Press.
- Dismukes, K. (2006). Concurrent task management and prospective memory: Pilot error as a model for the vulnerability of experts. Human Factors and Ergonomics Society 50th Annual Meeting, San Francisco, CA.

- Doherty, P. J. (2001). *Electronic checklist on multi-purpose displays: A better way for fighter pilots to manage information and situational awareness during periods of high workload* (Monograph. 1 Reynolds Ave Fort Leavenworth, KS 66027: USA Command & General Staff College School of Advanced Military Studies).
- Dornan, W. A., Beckman, W., Gossett, S., & Craig, P. (2007). *The implementation of the FAA industry training program in technically advanced aircraft (TAA): Lessons learned*. Middle Tennessee State University Department of Airspace, 1500 Greenland Drive, PO Box 67 Murfreesboro, Tennessee, 37132: Middle Tennessee State University. Retrieved September 17, 2008, from [http://www.faa.gov/education\\_research/training/fits/research/](http://www.faa.gov/education_research/training/fits/research/)
- Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 37(1), 32-64.
- Fiduccia, P., Wright, R., Ayers, F., Edberg, J., Foster, L., Henry, M., et al. (2003). *General aviation technically advanced aircraft FAA-industry safety study, final report* (Final Report of TAA Safety Study Team Federal Aviation Administration).
- Fleetwood, M.D., & Byrne, M.D. (2004). An Analyses of Two (or three) Models of Visual Attention Allocation. *Sixth International Conference on Cognitive Modeling*, 404--405, Mahwah, NJ: Lawrence Erlbaum.
- Freed, M. (2000). Reactive prioritization. *2nd NSA International Workshop on Planning and Scheduling in Space*. San Francisco, CA.
- French, J., Blickensderfer, B., Ayers, F., & Connolly, T. (2005). *FITS combined task 1&2 final report*. College of Art and Sciences College of Aviation, Embry Riddle Aeronautical University, Daytona Beach, FL 32114: Embry Riddle Aeronautical University. Retrieved September 17, 2008, from [http://www.faa.gov/education\\_research/training/fits/research/](http://www.faa.gov/education_research/training/fits/research/)
- Funk, K., Suroteguh, C., Wilson, J., Lyall, B. (1998). Flight deck automation and task management. *1998 IEEE International Conference on Systems, Man, and Cybernetics*, October 11-14, 1998.
- Hancock, P. A., Williams, G., & Manning, C. M. (1995). Influence of task demand characteristics on workload and performance. *International Journal of Aviation Psychology*, 5(1), 63-68.
- Horrey, W.J., Wickens, D.C., & Consalus, K.P. (2006). Modeling drivers' visual attention while interacting with in-vehicle technologies. *Journal of Experimental Psychology: Applied* 2006, (12)2. 67-78.

- Iani, C., & Wickens, C. D. (2004). Factors affecting task management in aviation. Technical Report AHFD-04-18/NASA-04-7 Dec 2004.
- Jensen, D. (2005, October 1). F-35 integrated sensor suite: Lethal combination. *Avionics Magazine*. Retrieved September 17, 2008, from <http://www.aviationtoday.com/av/categories/military/1145.html>
- Johnson, N.R., Wiegmann, D.A., Wickens, C.D. (2005). Effects of advanced cockpit displays on general aviation pilots' decisions to continue Visual Flight Rules (VFR) flight into Instrument Meteorological Conditions (IMC). Final Technical Report AHFD-05-18/NASA-05-6.
- Kent, J. (2006). The new front office: A whole new view for Joint Strike Fighter pilots. *Code One 21*(2). Retrieved September 17, 2008, from [http://www.codeonemagazine.com/archives/2006/articles/apr\\_06/front-office/index.html](http://www.codeonemagazine.com/archives/2006/articles/apr_06/front-office/index.html)
- Lee, Y., Lee, J.D., & Boyle, L.N. (2007). The effect of voice interactions on drivers' guidance of attention. Proceedings of the Fourth International Driving Symposium on Human Factors in Driver Assessment Training and Vehicle Design.
- Mosier, K. L., Skitka, L. J., Heers, S., & Burdick, M. (1998). Automation bias: Decision making and performance in high-tech cockpits. *The International Journal of Aviation Psychology*, 8(1), 47-63.
- Olson, W. A. (2001). Identifying and mitigating the risks of cockpit automation. *Air Command Staff and College Wright Flyer Paper no 14*.
- Prinzel III, L.J., & Risser, M. (2004). Head-up displays and attention capture. NASA/TM-2004-213000 February 2004.
- Rigner, J., & Dekker, S. (2000). Sharing the burden of flight deck automation training. *The International Journal of Aviation Psychology*, 10(4), 317-326.
- Robertson, C. L., Petros, T. V., Schumacher, P. M., McHorse, C. A., & Ulrich, J. M. (2006). *Evaluating the effectiveness of FITS training*. University of North Dakota. Retrieved September 17, 2008, from [http://www.faa.gov/education\\_research/training/fits/research/](http://www.faa.gov/education_research/training/fits/research/)
- Sarter, N. B., & Woods, D. D. (1992). Pilot interaction with cockpit automation: Operational experiences with the flight management system. *The International Journal of Aviation Psychology*, 2(4), 303-321.

- Sarter, N. B., & Woods, D. W. (1994). Pilot interaction with cockpit automation II: An experimental study of pilots' model and awareness of the flight management system. *The International Journal of Aviation Psychology*, 4(1), 1-28.
- Sarter, N. B., Woods, D. D., & Billings, C. E. (1997). Automation surprises. In G. Salvendy (Ed.), *Handbook of human factors & ergonomics* (Second Edition ed., pp. 1926-1943). New York: Wiley.
- Sarter, N. B. (2000). The need for multisensory interfaces in support of effective attention allocation in highly dynamic event-driven domains: The case of cockpit automation. *The International Journal of Aviation Psychology*, 10(3), 231-245.
- Sarter, N. B., Mumaw, R. J., & Wickens, C. D. (2007). Pilot's monitoring strategies and performance on automated flight decks: An empirical study combining behavioral and eye-tracking data. *Human Factors*, 49(3), 347-357.
- Spencer, C. F. (2000). *Cockpit automation and mode confusion: The use of auditory inputs for error mitigation*. Thesis. Air Command and Staff College, Maxwell AFB, AL 36112: Air Command and Staff College.
- Tenney, Y. J., Rogers, W. H., & Pew, R. W. (1998). Pilot opinions on cockpit automation issues. *The International Journal of Aviation Psychology*, 8(2), 103-120.
- Wickens, C.D., & Ververs, P.M. (1998). Allocation of attention with Head-Up Displays. DOT/FAA/AM-98/28.
- Wickens, C. D. (2000). *Imperfect and unreliable automation and its implications for attention allocation, information access and situation awareness*. (No. ARL-00-10/NASA-00-2).
- Wickens, C. D. (2002). Situation awareness and workload in aviation. *Current Directions In Psychological Science*, (11)4, August 2002.
- Wickens, C. D., Alexander, A. L., Thomas, L. C., Horrey, W. J., Nunes, A., Hardy, T. J., & Zheng, X. S. (2004). Traffic and flight guidance depiction on a Synthetic Vision System display: The effects of clutter on performance and visual attention allocation. Technical Report AHFD-04-10/NASA(HPM)-04-1.
- Wilson, G. F. (2002). An analysis of mental workload in pilots during flight using multiple psychophysiological measures. *International Journal of Aviation Psychology*, 12(1), 3-18.

Yeh, M., Wickens, C.D., & Seagull, F.J. (1999, December). Target cueing in visual search: The effects of conformality and display location on the allocation of visual attention. *Human Factors*, (41)4, 524-542.

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